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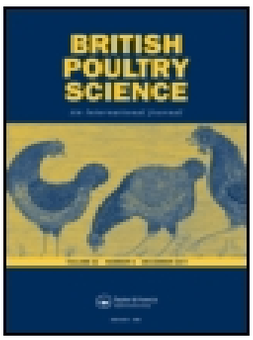

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Management and biosecurity practices by small to medium egg producers in Scotland

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ABSTRACT

1. Information about procedures and biosecurity practices used by small and medium egg producers (SMEPs) is scarce. Anecdotal evidence suggests that biosecurity in such enterprises may be poor, as personnel and equipment move freely between sites and this may be compounded by personnel working on commercial units who keep their own poultry.
2. To fill this gap in knowledge, a questionnaire was designed and implemented targeting SMEPs in Scotland. Small enterprises were defined as egg producers that have ≥50 laying hens but <350 laying hens; while medium enterprises were defined as egg producers that have ≥350 laying hens but

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≤32000 laying hens. The questionnaire consisted of a total of 56 questions divided into multiple sections, covering the characteristics of the primary keeper, location of the enterprise and size of the flocks, husbandry, marketing of products and health/biosecurity.

3. The questionnaire was posted to 375 holdings at the beginning of March 2017 and the survey remained open until the end of May 2017. In total 90 questionnaires were received by the cut-off date of which 76 questionnaires were from SMEPs. Forty were small enterprises and 36 were medium enterprises. For three questionnaires, it was not possible to identify the enterprise type.
4. Differences were observed between SMEPs in terms of reported biosecurity and management practices, with medium enterprises reporting the adoption of more biosecurity measures than small enterprises. Furthermore, SMEPs behave differently from backyard poultry keepers and large commercial companies in terms of disease risk.
5. In conclusion, it is important to ensure that SMEPs are considered in contingency plans and disease control programmes and that engagement with them is promoted so that the uptake of relevant information, such as awareness of disease control programmes, is optimised.

Keywords: egg producers, small to medium enterprises, biosecurity measures, poultry health

INTRODUCTION

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Disease recognises no borders and avian influenza (AI) and other exotic diseases have quickly spread throughout the world, becoming endemic in some countries. In order to develop epidemiological models of poultry disease spread and contingency plans, it is important to understand the biosecurity and movement practices of all aspects of poultry production.

The commercial poultry production sector in the United Kingdom (UK) is broadly separated into those companies producing eggs or meat. The commercial egg sector in the UK uses free-range systems for just over half of its production while the remaining eggs come predominantly from caged birds and a relatively small number of barn-type systems, in which birds are free to move around inside a poultry house but cannot access the outdoors (Anonymous 2019). From 2011 to 2013, 37,086 poultry premises (including both meat and egg-producing premises) were registered with local authorities in Great Britain (GB). Of these, 3078 premises were located in Scotland, with an average total of 24 million birds, based on census data (*i.e.*, average for specific points in each year), 10% of the total number of birds reported in GB). In 2012, the UK layer sector had around 6050 holdings and 43 million birds. In Great Britain most of the birds and holdings are located in England, while Scotland has around 393 (7%) layer holdings and 5,174,267 (14%) layer birds (Irvine 2015). In Scotland there were 6.8 million birds for egg production registered in the June 2018 Agricultural Census (Scottish Government 2018). The total output of egg production in Scotland was estimated to be £88.8 million in 2017 (the fifth largest livestock production output) and the majority of the holdings have fewer than 50 birds. Holdings with more than 50 birds are mostly located in the South East and South West regions of the country (Anonymous 2018).

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Commercial poultry enterprises of any significant size will typically use, as a minimum, biosecurity principles dictated by assurance schemes such as the Red Tractor scheme (Red Tractor 2019a; 2019b) and some information is available from the backyard poultry sector (Karabozhilova *et al.,* 2012; Correia-Gomes and Sparks 2020). Not much is known, however, about small to medium egg producers (SMEPs) in the UK. Anecdotal evidence suggests that biosecurity operated by SMEPs may be poor, as personnel and equipment move freely between sites, and this may be compounded by personnel working on commercial units who keep their own poultry. It is important to understand the potential links between the SMEP sector and large commercial enterprises. The current survey sought to address this gap by administering a questionnaire to understand more about the biosecurity practices employed by SMEPs and their knowledge of biosecurity and disease control.

The aims of this study were to gain insights about management and biosecurity practices of SMEPs in Scotland, to determine how these related to large commercial egg producers and to identify possible risks that SMEPs might pose to the larger poultry companies.

MATERIALS AND METHODS

Target population and sample size calculations

In the UK it is compulsory to register poultry flocks of 50 or more birds. Poultry included chickens, turkeys, ducks, geese, guinea fowl, quail, partridges, pheasants and pigeons. This requirement applies to birds being kept or bred for the consumption of meat and eggs, whether for personal or commercial use; any other commercial purposes; and restocking game birds. The requirement applies to birds being kept for any part of the year or all year-round (DEFRA 2018). Poultry keepers

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are registered in a national poultry register, which is kept by the Animal and Plant Health Agency (APHA), and which was used as a primary source of information for this study. This register includes the number and type of birds being kept as well as their purpose, production use, husbandry and management type. Furthermore, in Scotland, holdings with ≥350 laying hens need to be registered as laying egg establishments with Scottish Government's Rural Payments and Inspections Directorate (RPID) (Anonymous 2003) and have to fulfil some regulations related, to the Salmonella National Control Programme.

The target population for this study was Scottish poultry keepers, recorded in the APHA poultry register as of 9th October 2016, who had at least 50 and up to 32,000 chickens used for production of eggs. For the purpose of this study, all Scottish poultry keepers that identified themselves as producing table eggs were selected from the register list. A descriptive analysis of the number of egg-laying chickens on these premises in Scotland was done and the 90th percentile (32,000 egg laying chickens) was used as the cut-off from medium to large companies. After removing duplicates, the target population had 386 holdings. Based on the characteristics of the two key registration requirements and the analysis described above, small and medium egg enterprises were defined as follows:

- Small: ⩾50 laying hens but < 350 laying hens
- Medium: ⩾350 laying hens but ⩽ 32,000 laying hens.

Relatively little is known about the sample population. In order to calculate sample size, it was assumed that 50% of respondents would answer in the case of yes/no questions. Based on a desired confidence level of 95% and an error of ± 5%, the sample size was calculated to be 384. It was then adjusted for the population size and

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a non-response rate of 60%. The final estimated sample size was of 308 holdings, to give a desired number of respondents of 124. As the sample size was very close to the overall population (386 holdings), the postal questionnaire was distributed to the entire target population.

Questionnaire development

The questionnaire consisted of a total of 56 questions divided into two parts and seven sections. The sections covered the primary keeper, location of the enterprise and size of the flocks, husbandry, transport of birds, details about the enterprise, marketing of products, and health/biosecurity – with a list of 27 biosecurity measures. The questions were aggregated in these sections to provide answers related to exotic disease contingency planning (*e.g.*, unit location relative to other livestock farms, and estimated biosecurity level), and for endemic disease programmes (*e.g.*, identifying important poultry health issues for these keepers, the types of movements of birds from their farms, and approaches to biosecurity used). The questionnaire was available from March 2017 to May 2017 inclusive. Due to the Scotland-wide Avian Influenza (AI) Prevention Zone in place at the beginning of March 2017 (Defra 2017), the duplicates, questionnaire was divided into two parts: Part 1 included questions that the respondent was asked to answer based on what they were doing before the detection of the AI outbreak in the UK in 2016/17, while Part 2 included questions specifically related to how they were dealing with requirements of the AI Prevention Zone regulation.

Table S1 (Supplementary Material) gives a list of questions and their types. A combination of open and closed questions was used. For some questions, respondents were asked to choose only the most applicable answer, while for others they could select all options that applied to them. Most questions incorporating

'other' as a potential response offered the opportunity for the respondent to elaborate. For the sections dealing with moving birds to different locations and selling poultry products, the initial question established whether or not the section was relevant to the respondent and the remainder of the section could be ignored as appropriate. Copies of the final questionnaire are available upon request to the corresponding author.

Implementation of the survey

From the 386 holdings (target population), 10 were selected to pilot the questionnaire. A pilot questionnaire was sent by post and included a covering letter to explain the purpose of the survey. There were three respondents to the pilot survey. A fourth person made contact to explain that they no longer kept laying birds. Following the pilot, aspects of the questionnaire were amended to improve clarity. Responses provided in the pilot survey were not included in the final results. The address details for one holding were incomplete, so this holding was removed from the master list. The amended questionnaire was sent to the remaining 375 holdings at the beginning of March 2017 (see Table S2 in Supplementary Material for information about the postcode areas). Survey responses were collected until the end of May 2017. Questionnaires were posted with a covering letter explaining the purpose of the survey and return envelope enclosed. At the beginning of May a postal remainder was sent to all postal addresses in the sampling frame (except those that by the end of April had identified themselves as no longer keeping birds by contacting the authors of this study or 'Addressee gone away').

Data analysis

Descriptive statistics were generated for all the variables in the dataset. Results were summarised for each question using counts and percentages for categorical variables

and a summary of descriptive measures (*e.g.*, mean, median) for quantitative variables. The denominator for the descriptive statistics presented below varied, according to the numbers of respondents to each question. The denominator for questions concerning moving poultry to different location and selling poultry products was the number of respondents who had initially indicated that they sold or transported poultry. Where respondents could choose more than one answer, the denominator was kept as the number of respondents to the question, therefore, the percentages do not add up to 100%. Chi-squared or Fisher tests (when the assumptions for chi-squared test were not fulfilled) were used to determine whether there were any statistically significant differences in responses from small and medium producers. An ANOVA test was used to test for differences in age for the different knowledge categories. In all cases, a P value <0.05 was considered to be statistically significant.

RESULTS

Survey response

Of the 375 questionnaires mailed out, 10 were returned as incorrectly addressed and 18 responded to say that they no longer kept birds, they had less than 50 birds or they now only produce meat. In total 90 completed questionnaires were received by the cut-off date, of which 76 questionnaires met our target criteria for inclusion ($\geq$50 but less than or equal to 32,000 hens). Forty were classified as coming from small enterprises and 36 from medium enterprises. Three further questionnaires were included in the analysis although they did not provide the number of birds being kept on their premises. This was done because they identified themselves as commercial egg producers. The questionnaire response rate was around 25% (90/357).

The response rate for some questions was low (see Table S1): this needs to be taken into account in the interpretation of results reported for these questions.

Representativeness

The respondents came from 13 of the 16 Scottish postcode areas. No responses were received from Shetland, Motherwell and Outer Hebrides postcode areas, although questionnaires were sent to individuals in these locations.

The postcode areas with a highest response rates, based on the total of responses received, were Aberdeen (17.7%), Inverness (17.7%), Kirkcaldy (11.4%) and Galashiels (10.1%). Areas with the lowest response rates were Kilmarnock (1.3%) and Kirkwall (1.1%). No statistically significant differences were observed between the proportions of questionnaires received from the different Scottish postcode areas in relation to the number sent to each postcode area (P=0.093).

Respondents' demographics

Most of the respondents were males but there was an even spread of respondents under the age categories provided. However, 61.1% of the respondents from medium enterprises were less than 55 years old compared to 32.5% of the respondents of small enterprises. Almost all respondents identified their role as owners of the units. Most of the respondents had no formal training in poultry production, although this was skewed with the number being greater for small enterprises (80%) than medium enterprises (50%) (Table 1).

Table 1 here

Poultry keeping activities

Almost all the respondents (96% overall) had been working with poultry for more than one year, with a median of 16 years of experience overall (20 years for small versus 11.5 years for medium enterprises). The size of the flocks, referring to 2016, varied considerably over the year, from a minimum of 12 to a maximum of 29,000 birds, but the overall median flock size was 265 birds. The number of birds kept varied considerably between producer type, where small enterprises had a median of 77 birds while medium enterprises had a median of 4000 birds. Most of the respondents (88.6% overall) used commercial egg hybrid strains (median flock size of 240), followed by pure breeds (16.5% of respondents, with median flock size of 45), types of birds other than chickens (*e.g.*, turkeys, ducks, geese; 19% of respondents, with median flock size of 23.5) and exotic/rare breeds (6.3% of respondents). However, pure breeds and other type of birds were more frequently associated with small (27.5% and 32.5% respectively) than medium sized enterprises (5.6% and 5.6% respectively). Only the difference between enterprise for 'other type of birds' was statistically significant (P=0.04).

The majority of the respondents (72.2% overall) were not registered with a separate egg packer. This was more common for small enterprises compared to medium enterprises (90% *versus* 55.6% respectively, P<0.001).

Results from Part 1: Activities prior to the 2016-2017 UK avian influenza outbreak;

poultry husbandry

The majority of respondents (57% overall) mixed birds of different ages on the same site. Only 39.2% follow an 'all-in-all-out' policy. In small enterprises a mix of birds of different ages was quite common (70%), while following an 'all-in-all-out' policy

was more common for medium enterprises (55.6%). These differences between producer type were statistically significant (P=0.004).

With regard to how poultry were kept, respondents could choose several options. Most of the respondents (81% overall) classified their production type as free-range. Only two respondents (both from medium enterprises) housed their poultry in enriched cages. Almost 85% of all respondents reported that their birds did not have access to ponds, rivers/burns or lagoons/wetland/moving water. Of those respondents whose birds did have access to water, nine (50%) kept ducks as well as chickens. The chicken types with access to water were commercial egg hybrids, exotic or rare breeds and pure breeds.

When asked about what type of housing was available to avoid predators, the most common measures were housing the poultry at night (92.4% overall) and keeping them within electric or non-electric fences (35.4% and 27.8% respectively). Around 33% of all respondents reported having an active control programme for predators. The programmes varied from fox and rodent control, using cage traps, shooting predators personally or collaborating with gamekeepers to keep predator levels under control. Even so, around 28% of all respondents reported that they frequently (several times a year) lost poultry to predators. Only 15.2% of all respondents reported never having lost poultry to predators. The most common type of predator seen were foxes (82.1%), followed by birds of prey (25.4%) and badgers (22.4%).

The most common litter material was wood shavings (72.2%), followed by straw (35.4% - mostly small enterprises, P=0.002) and sawdust (25.3%). With regard to feed type, the most common feed type was pelleted compounded meal (53.2% - mostly small enterprises, P<0.001), followed by compounded mash in dry form (39.2% - mostly medium enterprises, P=0.004) and part/whole grain cereals (30.4% -

mostly small enterprises, P=0.04). The poultry feed was mostly sourced from specialised suppliers (87.3%). The most common manure management procedure was to spread it on fields (70.9%), followed by composting (41.8%). Composting was more frequent in small enterprises than medium enterprises (62.5% versus 19.4% respectively, P<0.003).

Moving poultry

Only approximately 5% of all respondents had not moved their poultry in the last 12 months, all from small enterprises. Sixty-six (83.5%) respondents moved live poultry onto their premises, 59.5% moved live poultry off their premises and 3.8% moved live poultry off their premises that then returned them. The median number of times and live birds that respondents moved onto, off or off and returned to their premises were two times (320 live birds), two times (3350 live birds) and three times (57.5 live birds), respectively. Medium enterprises moved more birds than small enterprises, but the frequency of moves did not differ. The most common reasons for moving live poultry were when restocking/buying (85.3% overall) and when depleting/selling (56% overall). Only two respondents reported 'taking part in shows' as a reason for moving live poultry. The average distance travelled by all respondents was 94.35 miles, while the maximum distance travelled was on average 171.7 miles. However, there was marked differences between small or medium enterprises (Figure 1), whereby medium enterprises travelled a greater distance when moving poultry compared to small enterprises (P=0.003 and pP0.0001 for average and maximum distance, respectively).

Poultry keepers tended to source and sell live poultry mainly within Scotland, although some traded into England. Almost 30% of the respondents did not reply to the question of how they moved their live poultry. Those that did, reported using a

specialist haulier (37.3%) or own vehicle (33.3%). There was a statistically significant difference (P<0.0001) between the farm types regarding how they moved their live poultry, whereby 72.2% of medium enterprises used a specialist haulier while only 2.5% of small enterprises did the same. When asked where they sourced their live birds, the majority (82.3% overall) obtained them from specialist pullet providers. Overall, only 26.6% of respondents reported sourcing hatching eggs, and these were sourced mostly from within the poultry keeper's own unit.

Poultry enterprise

The majority of respondents (84.8%) classified their poultry-keeping activities as the production of table eggs for commercial purposes. Around 13% of respondents (most of which were small enterprises) classified themselves as producing rare, pure or similar breeds for sale. Only 8.9% of all respondents reported producing or selling point of lay pullets. Around 65% of respondents reported having a second person involved in working with their poultry, and only 3.8% overall (all of which were medium enterprises) reported having five people working with their poultry.

On average, the hours spent per week in poultry keeping activities varied from 14 to 17 hours for all people on the poultry unit. The tasks varied greatly, from egg picking to husbandry and feeding. Almost 89% of respondents reported that people working with their poultry did not have contact with other birds. Only 8.9% reported that people working with their poultry had contact with other birds, mostly at their homes.

Sixty-four respondents (81%) had at least one other livestock species. The most common species were sheep (59.5%), cattle (45.6%), horses (34.2%) and pigs (24.1%). There were no major differences between enterprise types, with respect to other livestock on their farms. The number of animals kept varied greatly, but

median values were 140 sheep, 60 cattle, three pigs, and three horses. Fifty-two (65.8%) of respondents reported having one to five farms as neighbours within one mile of their location, with the most common livestock on these neighbouring units were beef and sheep. Around 47% of respondents reported having one to five, non-commercial poultry keepers as neighbours within one mile of their farms. This was more frequent for small enterprises (65%) compared to medium enterprises (44.5%), albeit not statistically significant.

When asked if they felt like part of the British poultry industry, 62% of respondents overall reported that they did, mostly because they produced on a commercial scale, were members of poultry associations, sold eggs and/or follow rules. The 38% of respondents that did not consider themselves as part of the British poultry industry mentioned their small production as the primary reason for this. Medium producers were statistically significantly more likely to consider themselves part of the British poultry industry than small producers ($P<0.0001$).

Selling poultry products

When asked how they sell their eggs, there were differences between types of enterprise ($P<0.0001$). The most common procedure was to sell directly from the farm (62% - mostly small enterprises), to local shops (31.6% - mostly medium enterprises) or to packing centres (27.8%). The majority of the medium scale producers sold their eggs to packing centres; however, none of the small-scale producers sold their eggs through this route.

The majority of respondents (62% - mostly small enterprises) kill their poultry on site, for welfare reasons, and the most common method is cervical dislocation (79.6%). However, four respondents mentioned they used pliers or similar methods, one of these being a medium scale producer. This method is illegal in UK

(Anonymous 2012). Only three respondents had a certificate of competence to slaughter or kill animals or a Welfare of Animals at the Time of Killing (WATOK) licence, and only 10 respondents had attended a specialised course on how to humanely kill poultry.

The majority of respondents (51.9%) disposed of their dead/culled poultry through a slaughter house or the National Fallen Stock Company (NFSCo). This occurred more frequently for medium scale producers (83%, $P<0.0001$) than for small scale producers (25%). Other methods of disposal were burying (17.7%) and incineration (15.2%). These last two are only allowed in Scotland in remote areas (Anonymous 2011), which was the case for some of the respondents. Two respondents mentioned that they fed carcasses to wildlife and another mentioned they fed them to their dogs. These procedures are illegal in UK (Anonymous 2011).

Poultry health and biosecurity

In general, only a few respondents rated their knowledge about poultry health, nutrition, legislation and biosecurity as low (3.8%, 7.6%, 7.6% and 1.3% overall, respectively). The majority of respondents (57% overall) rated their knowledge about biosecurity as high. It was notable that, of the three respondents who fed dead birds to wildlife or dogs, two reported their biosecurity knowledge as medium and one as high. Respondents from medium scale enterprises typically rated their knowledge in the different topics as high compared to respondents of small enterprises. However, there were only statistically significant differences between enterprise type for self-assessment of legislation knowledge ($P=0.025$). The respondents' main source of information about poultry health was the veterinarian (for 50.6% of all respondents and 66.7% of medium scale enterprises), followed by

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books and magazines (15.2% overall) and then poultry-keeping friends (11.4% overall).

Around 80% of respondents had rarely or never seen respiratory, digestive or locomotor problems, high mortality rates or sudden decrease in production in their poultry. Behaviour problems and internal parasites were uncommon, as 63.3% and 68.4% of respondents overall reported rarely or never have seen these in their birds, respectively. External parasites (*e.g*., red mite) were the only ailment reported by 50.6% of respondents to have been seen frequently or sometimes. However, compared with small enterprises, behaviour problems, external and internal parasites were significantly more frequently seen in medium enterprises (P=0.004, P=0.010, P=0.011, respectively).

When asked how frequently owners consulted their veterinarian, around 37% of respondents stated at least once a year, 33% reported less than once a year and 24% reported never having consulted a veterinarian for their poultry. There were statistically significant differences between enterprises (P<0.0001), whereby medium enterprises consulted a veterinarian more frequently than small enterprises.

In terms of routine procedures, de-worming and treatment for external parasites, these were reportedly done routinely by 36.7% and 34.2% of all respondents, while 29.1% and 41.8%, respectively, reported only doing these when necessary. Routine de-worming was more common in small enterprises than in medium enterprises (P=0.04). Around 54% of all respondents reported not treating for coccidiosis, while 69.6% reported not using antibiotics. The use of antibiotics was reported only when necessary by 19% of respondents, and they used mostly antibiotics advised by their veterinarian. The active ingredients used included tylosin, oxytetracycline, tiamulin

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and amoxicillin. No statistical difference was discernible between small and medium enterprises in the frequency of antibiotic use.

Most of the poultry were vaccinated before purchase, with 72.2% of all respondents and 88.9% of respondents from medium enterprises reporting this practice. Medium enterprises were significantly more likely to report this practice than small enterprises (P=0.005). The vaccines used mostly were active against salmonellosis, Marek's disease, erysipelas, coccidiosis and respiratory pathogens (*e.g.*, Newcastle disease, infectious bronchitis, infectious laryngotracheitis and pasteurellosis). Respondents sourced their medications mostly from veterinarians (50.6%) or specialised shops/suppliers (39.2%). The former was more common among medium enterprises while the latter was more common among small enterprises (P=0.015).

Twenty-seven biosecurity measures were proposed in the questionnaire. The complete list of results for this question is available in Supplementary Information (Table S3). Two respondents reported implementing all of these at least sometimes and all respondents had implemented at least one of these measures occasionally. A median of 20 measures were implemented at least sometimes (18 by small enterprises and 23 by medium enterprises).

The most popular biosecurity measures, which were always or usually implemented by at least 80% of all respondents, were the provision of clean water, control of rodents, sourcing birds from reputable sources, taking measures to stop wildlife accessing feed or waste areas and washing hands after handling poultry. Whilst the least popular measures, which were always or usually implemented by fewer than half of all respondents, were thoroughly cleaning and disinfecting shared equipment before use, operating an all-in all-out policy when restocking, isolating new stock, making provision to ensure visitors vehicles were clean when entering property and

using specific/clean footwear when visiting poultry of different ages on the same site (Table S3). New stock was isolated for a median of four weeks and poultry housing was cleaned two times per month.

For certain biosecurity measures, there were statistically significant differences in implementation levels between small and medium enterprises (Table 2). Cleaning out poultry housing was more commonly adopted by small in comparison with medium enterprises.

When asked in terms of disease control what producers would consider the biosecurity perimeter to be, 49.4% considered it to be the flock, 22.8% the poultry unit and 16.5% the whole enterprise. Two respondents considered it to be a combination of the flock and the unit or the unit and the enterprise. There was no statistical difference between small and medium enterprises.

Most of respondents (>50% overall) had rarely or never seen neighbours' poultry, livestock, rodents, water birds, geese and gulls within 100 metres from where they keep their poultry. Only pigeons were seen monthly by 17.7% of respondents. However, rodents and geese were seen mostly at certain times of the year by 20.2% and 24.1% of respondents, respectively. This was consistent with the majority of respondents (86.1%) reporting lack of awareness of any wild bird reserve within 3 km of their site. However, 13.9% reported a wild bird reserve near their location.

There was no statistical difference between small and medium enterprises for predators or potential reservoirs of disease. The main concern about poultry health reported by respondents was avian influenza.

Results from Part 2: Responses to the Avian Influenza Protection Zone regulation in Scotland

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A key requirement of the Scotland-wide Avian Influenza Protection Zone regulation was that all poultry be housed indoors. With regard to the outbreak of AI and the housing order, almost 92% of respondents reported that they were able to house their birds. Only five small enterprises reported that this was not possible, mainly due to impracticality and sheds that were too small to accommodate all the birds. The biggest husbandry problems reported by respondents were cleaning sheds, poultry being 'bored' and aggression/feather pecking. Behaviour problems were most commonly reported by medium enterprises. To deal with these husbandry problems, the respondents reported having to provide an enriched environment (*e.g.*, using toys, extra bedding), changing building features and more regular cleaning of the housing.

DISCUSSION

The objective of this study was to characterise the SMEP sector in Scotland and to better understand their role in national biosecurity. The husbandry, management and biosecurity associated with SMEPs in Scotland were characterised, with a focus on the potential risk posed to the poultry industry on a larger scale.

The response rate to this questionnaire was around 25%, which was lower than the estimated response rate used for the sample size calculations (40%). This could have influenced the results derived by the questionnaire, as the high percentage of non-responses could be a source of selection bias. No statistically significant difference was observed for the proportion of completed questionnaires received from the different Scottish postcode areas in relation to what was originally sent, which should have reduced the risk of bias in terms of location. Furthermore, it was possible to observe expected differences between small and medium producers. This

confirmed that these results could be extrapolated to Scotland as a whole. This was a self-administered questionnaire, which can decrease the response rate when the questionnaire subject is not interesting enough to the respondents; however, the overall non-response rate per question was low (Table S1). Another limitation of the self-administered questionnaires was the difficulty in validating respondents' answers, so the responses reported may represent the best-case scenario.

The questionnaire was available from March 2017 to May 2017 inclusive. At the beginning of December 2016, a Scotland-wide Avian Influenza (AI) Prevention Zone was in place, requiring that all poultry and captive birds be kept indoors, or otherwise kept separate from wild birds. This prevention zone was lifted at the end of April 2017 (DEFRA 2017); therefore the survey was carried out while the prevention zone was still in place. Although survey participants were asked to answer Part 1 of the questionnaire based on what they were doing before the UK AI outbreak, these responses might not accurately reflect their routine procedures (*e.g.*, biosecurity might have increased due to the AI outbreak (Knight-Jones *et al.*, 2011) or they may have reported that they were more knowledgeable about biosecurity because it was topical at the time).

The demographics of the survey respondents were adult males over 35 years old, with no formal training, but working with poultry for a long time. This was consistent with previous findings about agricultural workers in Scotland (Anonymous 2018). Other sorts of training, such as in-house courses, were reported by medium enterprises, which suggested some degree of training was provided or encouraged by this type of enterprise, possibly encouraged in part by the requirements of assurance schemes. The overall lack of formal animal welfare training (especially in relation to culling animals) and the use of inappropriate

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culling techniques by a small number of producers may have indicated a lack of knowledge in this area. It is important to ensure that proper advice is provided regarding culling techniques and this should be considered by the authorities and industry.

The size of the flock varied considerably with the type of enterprise and, as expected, medium enterprises had bigger flocks of mainly commercial hybrid hens. There were some features of the small-scale enterprises which could signify an increased risk for disease transmission in the event of an infectious disease outbreak, such as AI. These were, most notably, an increased likelihood to have a variety of poultry species, which was relevant due to differing susceptibilities to AI among different species (Nuñez and Ross 2019). In addition, increased likelihood that birds would have access to ponds/rivers/other outside water sources where they could come into contact with wild birds or other wildlife and an increased likelihood that birds of different ages would be present on the same site, as susceptibility can vary with age (Hill *et al.*, 2016) and disease can be transmitted from older birds to younger birds and *vice-versa*.

Almost half of the medium sized enterprises were associated with a major egg company. Such an association generally required adherence to a range of procedures, including biosecurity, as an integral part of contract arrangements (East 2007) and, therefore, it was not surprising that most of the medium enterprises considered themselves as part of the British poultry industry and reported that their knowledge about biosecurity was high. The opposite was observed for small enterprises and this lack of engagement with commercial entities may impair their uptake of the most recent technology or advice available.

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The percentage of free-range flocks was quite high compared to, for example, the US (Garber *et al.*, 2009). It was difficult to draw comparisons based on flocks numbers, as most of the reported statistics worldwide have been based on number of birds, and the UK is one of the countries in Europe with the highest number of laying hens housed in free range systems (Anonymous 2013).

Another difference between enterprises was the number of birds moved to and from their location, which was higher for medium compared with small enterprises, and the distances moved were different. Movement of animals is a known risk for disease introduction and spread (Ssematimba *et al.,* 2013) and, if not associated with high biosecurity practices (*e.g*., buying from only one source and selling to the same destination), can lead to spread of disease throughout the entire industry (Ssematimba *et al.*, 2013). It was interesting to note that small enterprises were likely to move birds just as often in a 12-month period as medium enterprises. Thus, although the number of individual birds involved was likely to be lower, there were still as many opportunities for movement-associated disease transmission risk among small as for medium enterprises. Differences between enterprises were observed for the use of specialist hauliers for the movement of birds, as although this was common practice for medium enterprises, it was rarely used by small enterprises. Specialist hauliers should adhere to strict cleaning and disinfection procedures to reduce the risk of disease transmission through indirect contact between farms. However, work in other sectors has shown that this is not usually the case and can actually increase the risk of disease transmission (Porphyre *et al.*, 2019).

Manure management was not ideal, as the most common procedure was to spread it on fields, which can be associated with disease spread (Kyakuwaire *et al.*, 2019). Although rare, both type of enterprises reported having employees who kept birds at

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home, similar to other reports (Garber *et al.,* 2009). Such personnel have featured in previous highly pathogenic AI outbreaks in the UK (APHA 2015). This practice can pose a risk for disease transmission from backyard poultry keepers to the commercial poultry sector and *vice-versa*. A similar risk of disease transmission exists when several bird species or other livestock animals are kept in the same location as laying hens. This is likely to increase on-site traffic, potentially leading to a greater risk of infectious disease transmission. The most common livestock species kept were sheep, cattle and horses, although some respondents reported having pigs. Avian influenza and other viruses can easily be transmitted between pigs and poultry increasing the risk for mutation and adaptation to human hosts (Nuñez and Ross 2019). Proximity to other livestock herds can constitute a risk for airborne diseases (Ssematimba *et al.,* 2013). Proximity to non-commercial poultry keepers (within one mile of their location) was more frequent in small than in medium enterprises (albeit, not statistically significant); while proximity to commercial poultry, pig, beef and sheep producers was similar between enterprises types. In case of disease incursion the proximity to backyard and commercial poultry producers increases the risk of disease transmission due to local spread (Ssematimba *et al.,* 2013).

Overall respondents rated their knowledge about poultry health, nutrition, legislation and biosecurity as medium to high. However, this seemed to be at odds with some of the respondents reporting illegal practices in relation to culling and disposal of poultry – particularly in the case of feeding culled poultry to wildlife or dogs, which has substantial implications for disease transmission. These practices indicated a lack of knowledge of the relevant legislation and suggested that authorities should make an effort to disseminate proper advice regarding poultry-keeping legislation more widely. Alternatively, respondents who carry out these practices may not perceive

their behaviours as a genuine risk to poultry health; which suggested some discrepancy between the delivery of information about the importance of safe disposal of carcases and the understanding of such messages by the producers it is aimed towards.

Disease was not reported to be prevalent in small enterprises flocks, while, for medium enterprises, it was more common to observe behaviour problems and external and internal parasites in these flocks. This may be due to higher stocking densities, greater disease awareness and more frequent or closer inspection of birds in medium enterprise flocks. External and internal parasites are among the most commonly reported disease problems in free-range hens (Singh *et al.,* 2017).

It is not surprising that medium enterprises reported regular contact with veterinarians as the main source of health information and of medication for these flocks. On the other hand, poultry in small enterprises were rarely seen by a veterinarian. This may have implications for disease spread, as it makes it possible for disease to could go unobserved for long periods of time before diagnosis, particularly if clinical signs were mild. It could have implications for the dissemination of poultry health-related messages, if the expectation was that veterinary practitioners are best placed to transfer such information to poultry keepers. Vaccination was a more common practice in medium enterprises, which indicated higher awareness to poultry health problems.

All respondents reported implementing at least one biosecurity measure out of a list of 27. In the majority of cases, these measures were not implemented comprehensively, which was similar to results reported elsewhere (Garber *et al.,* 2009; Singh *et al.,* 2017; Scott *et al.,* 2018). In comparison with backyard poultry keepers in Scotland (Correia-Gomes and Sparks 2020), SMEPs implemented more

biosecurity measures (a median of 15 measures for backyard keepers versus 20 for SMEPs). Biosecurity was higher for medium enterprises, especially for external factors (*e.g.*, visitor policy, protection against wildlife, vehicle cleaning, etc.) than for small enterprises. Small enterprises seem to behave, in terms of biosecurity, closer to backyard poultry keepers (Correia-Gomes and Sparks 2020). It would be interesting to compare these results with reported biosecurity for the commercial egg sector in Scotland. It was not within the scope of this survey to ask the respondents to elaborate on why they chose to implement certain measures suggested. This would be an interesting area to explore, to further understand the perceived barriers to implementation of measures that may, at first glance, be considered to be relatively straightforward as well as the extent of compliance. Compliance has been an issue identified in other studies (Sparks 2016; Racicot *et al.,* 2012) and what has been reported here in terms of biosecurity measures was likely to be the best-case scenario.

Almost 14% of respondents declared that they were aware of whether there were any wild bird reserves within 3 km of the site where they kept their poultry. Contact between domestic poultry and wild birds, water fowl in particular, has recently been associated with outbreaks of AI in the UK (APHA 2017). Furthermore, almost one quarter of the respondents had seen geese in certain months of the year close to their farm. Geese can shed AI virus asymptomatically and pose a particular threat to domestic poultry (Gaidet *et al.,* 2010).

The main concern expressed by respondents was AI, which may have reflected the fact that the survey was conducted during an outbreak in the UK. As the Scotland-wide AI Prevention Zone order (which required that all poultry and captive birds be kept indoors or otherwise separate from wild birds) was in place during most of the

survey, it was a good opportunity to ask about views related to problems posed by this order. Findings, in terms of respondents' ability to comply with the order and the main husbandry issues encountered, were similar to that reported in previous AI outbreaks, *i.e.*, welfare (Knight-Jones *et al.,* 2011). As AI outbreaks have been more common in Europe in recent years (Napp *et al.,* 2018) it would be worthwhile for the poultry industry and authorities to provide advice to poultry keepers on how to be prepared for these incursions. It is important that official requirements, such as housing of birds at a time of disease outbreak, are adhered to. This can be facilitated by an understanding of the practicalities of such an order for the range of enterprise types across the affected region.

The speed with which information about outbreaks is provided was an important consideration. Although engagement with authorities was not addressed in this questionnaire, feedback received from a webinar conducted to discuss the findings of the survey with this target population suggested that SMEPs tended not to subscribe to the AI Alerts service from APHA. It is possible that greater engagement across the poultry sector could be achieved at times of disease outbreak if further evidence could be gathered to understand why producers may not take advantage of rapid information services. An understanding of perceived barriers for complying with the protection zone order would provide valuable information regarding the advice given and obligations required of producers in the event of future disease problems.

Small and medium egg producers behave differently in terms of disease risk. In terms of implementation of biosecurity practices, small egg producers closely resemble backyard poultry keepers, while medium egg producers are more like large commercial companies. It is important to ensure that SMEPs are considered in

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contingency plans and disease control programmes and that engagement with them is promoted, so that the uptake of relevant information is optimised.

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Conflict of interest:

The authors declare no competing interest.

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Data availability statement

The data that support the findings of this study are available from the Madeleine Henry, [MKH – madeleine.henry@sruc.ac.uk], upon reasonable request.

List of Figures:

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Tables

Table 1: Demographics of the respondents for all the respondents and split by small and medium enterprises

	All respondents		Small enterprises		Medium enterprises		P value
Sex	N	%	N	%	N	%	0.281
Female	26	32.9	16	40.0	10	27.8	
Male	51	64.6	23	57.5	26	72.2	
NR	1	1.3	1	2.5	0	0	
Age							0.027
Under 35	0	0	0	0	0	0	
35-44	15	19.0	3	7.5	12	33.3	
45-54	20	25.3	10	25.0	10	27.8	
55-64	21	26.6	12	30.0	8	22.2	
65 and over	21	26.6	14	35.0	6	16.7	
NR	2	2.5	1	2.5	0	0	
Role							0.46
Manager	1	1.3	0	0	1	2.8	
Owner	75	94.9	39	97.5	34	94.4	
Owner+manager	1	1.3	0	0	1	2.8	
NR	2	2.5	1	2.5	0	0	
Training type							<0.001
No formal training	52	65.8	32	80.0	18	50	
Attended certified training/refresher short course(s)	5	6.3	1	2.5	4	11.1	
Attended further education (e.g. HNC/HND) course(s)	7	8.9	0	0	7	19.4	

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Attended higher education (e.g. BSc, MSc) course(s)	6	7.6	2	5.0	4	11.1
Attended non-certified training/refresher short course(s) such as in-house courses	2	2.5	0	0	2	5.6
Other	0	0	0	0	0	0
NR	7	8.9	5	12.5	1	2.8

Legend: N – counts, % - percentage, NR – non-response.

Table 2: Biosecurity measures taken by small and medium enterprises – numbers and (percentage).

	Small enterprises				Medium enterprises				P value
Strategy	**A+U (%)**	**S+N (%)**	**NA (%)**	**NR (%)**	**A+U (%)**	**S+N (%)**	**NA (%)**	**NR (%)**	
1.Operate an all-in all-out policy when restocking	11 (27.5)	16 (40)	8 (20)	3 (7.5)	24 (66.7)	5 (13.9)	4 (11.1)	3 (8.3)	0.006
2.Buy animals from reputable sources	34 (85)	1 (2.5)	3 (7.5)	2 (5)	35 (97.2)	0	0	1 (2.8)	0.425
3.New stock is isolated	22 (55)	5 (12.5)	4 (10)	9 (22.5)	12 (33.3)	3 (8.3)	13 (36.1)	8 (22.2)	0.044
4.Isolate any poultry that is showing signs of illness from healthy poultry	30 (75)	6 (15)	3 (7.5)	1 (2.5)	28 (77.8)	3 (8.3)	3 (8.3)	2 (5.6)	0.721
5.Limit the number of visits to other poultry units or livestock	21 (52.5)	4 (10)	14 (35)	1 (2.5)	27 (75)	3 (8.3)	3 (8.3)	3 (8.3)	0.021

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units									
6.Visitor access to poultry is restricted	24 (60)	8 (20)	7 (17.5)	1 (2.5)	33 (91.7)	2 (5.6)	0	1 (2.8)	0.002
7.Specific/clean clothing when accessing poultry area(s)	14 (35)	20 (50)	5 (12.5)	1 (2.5)	24 (66.7)	8 (22.3)	2 (5.6)	2 (5.6)	0.018
8.Specific/clean footwear when accessing poultry area(s)	15 (37.5)	19 (47.5)	5 (12.5)	1 (2.5)	27 (75)	7 (19.5)	0	2 (5.6)	0.001
9.Specific/clean footwear when visiting poultry of different ages on the same site	9 (22.5)	21 (52.5)	8 (20)	2 (5)	14 (38.9)	5 (13.9)	14 (38.9)	3 (8.3)	0.004
10.Hand washing before handling poultry	19 (47.5)	18 (45)	2 (5)	1 (2.5)	26 (72.2)	7 (19.5)	0	3 (8.3)	0.020
11.Hand washing after handling poultry	34 (85)	5 (12.5)	1 (2.5)	0	29 (80.6)	4 (11.1)	0	3 (8.3)	0.241
12.Provision of clean water to my birds	40 (100)	0	0	0	34 (94.4)	0	1 (2.8)	1 (2.8)	0.221
13.Clean out poultry housing	32 (80)	2 (5)	1 (2.5)	5 (12.5)	18 (50)	1 (2.8)	9 (25)	8 (22.2)	0.005
14.Disinfect housing between batches of poultry	27 (67.5)	8 (20)	3 (7.5)	2 (5)	34 (94.5)	0	2 (5.6)	0	0.004
15.Fence holding boundaries	27 (67.5)	3 (7.5)	6 (15)	4 (10)	30 (83.3)	0	3 (8.3)	3 (8.3)	0.335
16.Control rodents	35 (87.5)	1 (2.5)	2 (5)	2 (5)	36 (100)	0	0	0	0.245
17.Control insects	28 (70)	5 (12.5)	3 (7.5)	4 (10)	29 (80.6)	2 (5.6)	1 (2.8)	4 (11.1)	0.602
18.Take measures to	25	3	8 (20)	4 (10)	32	2 (5.6)	1 (2.8)	1 (2.8)	0.036

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stop wildlife accessing poultry or poultry accommodation	(62.5)	(7.5)			(88.9)				
19.Take measures to stop wildlife accessing feed or waste areas	31 (77.5)	2 (5)	3 (7.5)	4 (10)	33 (91.7)	2 (5.6)	1 (2.8)	0	0.280
20.Prevent contact between poultry and other animals on my holding	24 (60)	12 (30)	3 (7.5)	1 (2.5)	29 (80.5)	5 (13.9)	0	2 (5.6)	0.071
21.Prevent contact between my poultry and my neighbours' animals	27 (67.5)	2 (5)	10 (25)	1 (2.5)	33 (91.7)	0	2 (5.6)	1 (2.8)	0.023
22.Avoid exchanging live animals with neighbours/ friends	25 (62.5)	3 (7.5)	10 (25)	2 (5)	30 (83.4)	2 (5.6)	3 (8.3)	1 (2.8)	0.191
23.Avoid exchanging equipment with neighbours/ friends	25 (62.5)	2 (5)	11 (27.5)	2 (5)	29 (80.6)	3 (8.3)	3 (8.3)	1 (2.8)	0.131
24.Thoroughly clean and disinfect shared equipment before using it	14 (35)	1 (2.5)	22 (55)	3 (7.5)	20 (55.6)	0	15 (41.7)	1 (2.8)	0.232
25.No wild bird feeder on the property	20 (50)	9 (22.5)	8 (20)	3 (7.5)	25 (69.4)	3 (8.3)	5 (13.9)	3 (8.3)	0.261
26.Provision made to ensure visitor vehicle entering your property are cleaned	5 (12.5)	18 (45)	15 (37.5)	2 (5)	19 (52.7)	13 (36.1)	1 (2.8)	3 (8.3)	<0.001
27.Vehicles used to move poultry are	15 (37.5)	8 (20)	15 (37.5)	2 (5)	27 (75)	3 (8.3)	5 (13.9)	1 (2.8)	0.008

cleaned and disinfected after movement	

Legend: A+U – always (every time) and usually (20-99% of the time); S+N – sometimes (less than 20% of the time) and never; NA – non applicable, NR – nonresponse

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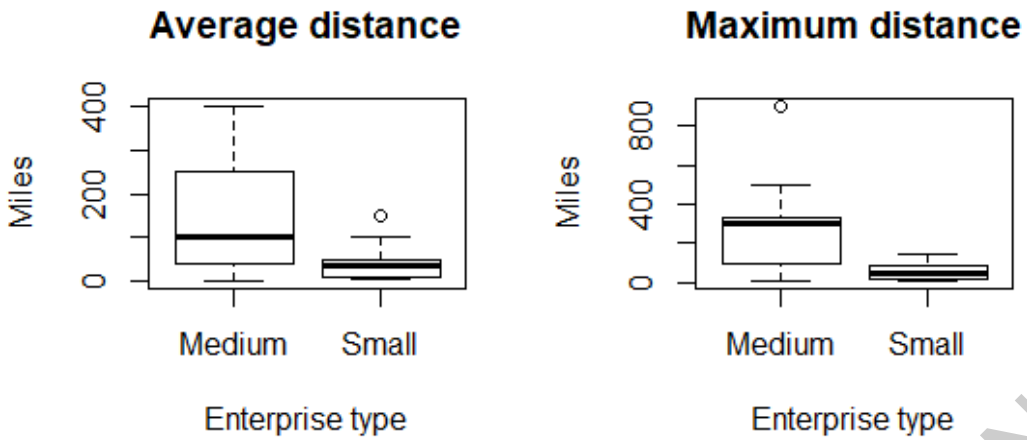

Fig 1

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