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ORIGINAL RESEARCH

Spatial and temporal analysis of sheep scab notifications in Scotland, 2014–2019

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Abstract

Background: Sheep scab is considered an endemic disease of great welfare and economic significance in the UK.

Method: This paper provides an up-to-date assessment of the impact of Sheep Scab (Scotland) Order 2010 on sheep scab notifications in Scotland between 1 January 2014 and 31 December 2019, using data collected by the APHA.

Results: In total, 564 sheep scab notifications were reported from 503 unique holdings, of which 44 holdings (8.7%) reported more than one incident. The number of notifications did not differ between years, with 81, 84, 93, 101, 109 and 97 notifications recorded in 2014, 2015, 2016, 2017, 2018 and 2019, respectively: representing an average annual notification prevalence of 0.63% (1/159 flocks/year). A total of 413/564 records documented how notifications were resolved, with macrocyclic lactone and organophosphate treatments accounting for 79.6% and 20.4% of resolutions, respectively.

Conclusion: Our results suggest that the Order has facilitated the notification of sheep scab in Scotland (including trends and preferred methods of resolution), allowed industry and government to identify previously unidentified potentially free areas as well as recurrent incidents on sheep farms, and start to understand better the geographical and temporal nature of scab outbreaks. However, concerns remain about a potential lack of engagement, evidenced by the low notification prevalence and stagnant annual notification rates.

INTRODUCTION

Sheep scab (ovine psoroptic mange), caused by infestation with the ectoparasitic mite *Psoroptes ovis*, is considered endemic in Great Britain (GB).[1–3] Affected sheep suffer from acute or chronic forms of allergic dermatitis,[4] resulting in extreme inflammatory reactions, characterised by rubbing, scratching and biting at lesions.[5,6] A stereotypic 'nibble reflex' can be elicited when sheep are handled, whereby sheep demonstrate a 'lip-smacking' behaviour, protruding their tongue and nibbling the air.[7] Such behaviours are considered key indicators of compromised animal welfare.[8] Infestations, often seen during the winter months,[4,9] result in reduced performance, weight loss, reduced weight gain and poor maternal performance.[10,11] In extreme cases, infestations result in death through fitting or hypothermia.[11] As such, the clinical manifestation of sheep scab incurs a high welfare cost.[8]

The financial burden to the GB sheep industry is also significant. The cost is estimated at between £78 and £202 million per annum,[12] most of which is attributed to the implementation of treatments and preventative measures.[13] The cost of individual flock infestations are high, ranging from £1000 to £2400 per 300 ewes in a lowland flock and £1000 to £2100 per 300 ewes in an upland flock.[12]

Welfare and production concerns have led to formalised sheep scab control and eradication programmes. Variations of both local and national legislation have been in place since 1870.[14] Legislation enforced during the early 20th century resulted in the eradication of sheep scab from GB in 1952.[11,14] However, the disease was reintroduced in 1973, resulting in a resurgence in national legislative control. This centred on autumn dipping (1976–1983), then summer and autumn dipping (1983–1989) and finally autumn dipping (1989–1992). By 1988, fewer than 40 cases were recorded nationally; however, after the removal of summer dipping, cases began to rise steadily.[9,14] Following deregulation in 1992, when cases were no longer notifiable, and routine preventative treatment was no longer a requirement, case numbers rose rapidly.[9,14] In response to concerns about increasing case numbers the Scottish sheep industry in conjunction with the Scottish Government developed an industry-led approach to sheep scab control, which ultimately led to the Sheep Scab (Scotland) Order 2010.[15] There are currently three pieces of legislation in the UK that aim to control the spread of sheep scab (Table 1).

Determining an accurate prevalence of sheep scab has been difficult since deregulation. A survey performed by the Sheep Veterinary Society in 1995 reported that approximately 3000 cases were seen annually in GB.[14] Other authors have determined recent national and regional prevalence, and identified a 9% national (UK wide) prevalence and a 12%–14% Scottish prevalence.[3,16]

TABLE 1 Current legislation for the control of sheep scab in the UK, including the region in which the legislation is enforced, and a summary of the conditions applied

Legislation	Region	Conditions of the legislation
Sheep Scab Order 1997	England and Wales	It is an offence to leave sheep visibly affected with sheep scab untreated. It is also an offence to transport visibly affected sheep unless sheep are transported for treatment or directly to slaughter.
Sheep Scab (Shetland Isles) Order 2003	Shetland Isles	The council requires advance notice of sheep arriving on the island from the mainland. On arrival, sheep may be subject to examination, testing and treatment for sheep scab and may not mix with any other sheep for 48 hours after arrival.
Sheep Scab Scotland Order 2010 (as amended in 2011)	Scotland (excluding Shetland)	The local APHA office must be immediately notified if any person(s) suspect that animals are infested with sheep scab. All sheep will then remain under movement restrictions until treated, slaughtered or a veterinarian reaches a negative diagnosis. Failure to comply will result in referral to the local authority.

Here we aimed to analyse available Scottish Government sheep scab notification data and associated metadata provided by the APHA from January 2014 to December 2019, thereby providing a spatial and temporal assessment of sheep scab notifications in Scotland made under the Sheep Scab (Scotland) Order 2010.

MATERIALS AND METHODS

Data sources and description

Sheep scab notification data and metadata

Separately, for years 2013–2014, 2015, 2016, 2017, 2018 and 2019, six datasets were provided by the APHA. An overview of the sheep scab notification process by which the data were collected can be found in Supporting Information 1, a summary of which is provided in Figure 1 and an example of the recording form (SS09) can be found in Figure S1. All datasets included a minimum amount of information pertaining to each notification (Table S1). The data analysed included all notifications raised in the complete years between 1 January 2014 and 31 December 2019. In addition, any rows within the dataset that did not have a unique SAM Work Schedule number (APHA's internal IT system), a complete county-parish-holding number (CPH) number or both were excluded from the analysis ($n = 2$).

Rural and Environment Science and Analytical Services Division datasets

The Rural and Environmental Science and Analytical Service (RESAS) provided five datasets: (i) a shapefile which defined the boundaries for both agricultural parish and county regions; (ii) a dataset identifying which parishes are included in a county; (iii) a dataset which included the total count of sheep, total count of holdings and the total count of sheep registered holdings for each county from 2014 to 2019; (iv) a dataset detailing the total number of hectares in agricultural use per county per year from 2014 to 2019; (v) a dataset detailing the total number of hectares in common grazing and the number of holdings with access to common grazing per county per year from 2014 to 2019.

Data analysis

All data analysis and visualisations were performed using R version 4.0.2 (http://cran.r-project.org/).[17] All data were analysed using the 'lme4', 'mgcv', 'ggmap' and 'ggplot2' packages within the R framework. A detailed description of data and metadata preprocessing can be found in Supporting Information 2.

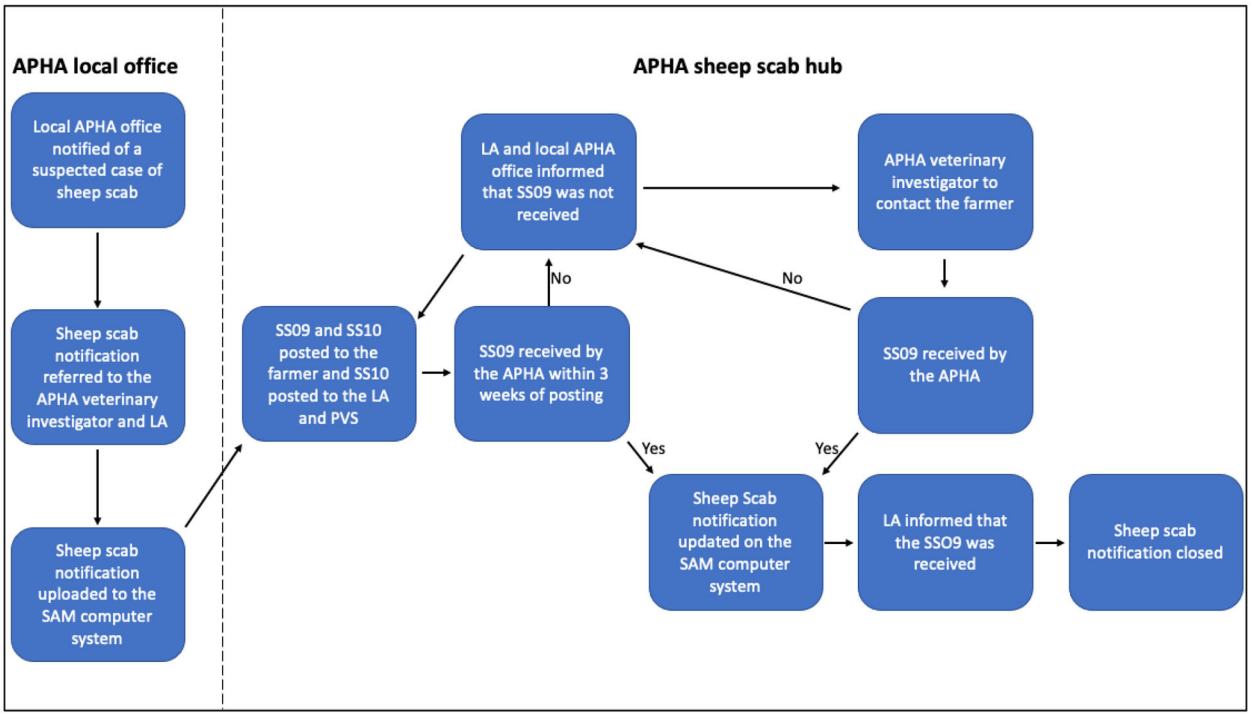

FIGURE 1 Flow chart of the current sheep scab notification workflow within and between the APHA, private veterinary surgeons (PVS) and the local authority (LA). The dotted line indicates the transition between different offices within the APHA or between the APHA and the LA. The SS10 is a letter sent to the keeper, PVS and LA which details (i) the conditions under which sheep movements are restricted, (ii) the available options that the keeper may take to resolve the notification and (iii) advice on best practice. The SS09 is a form sent to the keeper to fill in and return to the APHA

Temporal analysis

Here we were interested in the effect of 'Year' on the counts of sheep scab notifications and whether this effect generalises over counties. To this end, we fitted a mixed-effects Poisson regression model. Year (six levels: 2014–2019) was treated as a fixed factor and County (n = 33) as a random factor. Given that Year has an ordinal ('later than') interpretation, the five required effect parameters for this predictor were coded using a backward difference coding scheme. The random effect's structure included the by-County random intercept and by-County random slopes on Year. Random correlation parameters were also included, and significance was established via likelihood ratio model comparisons.

Denominator data

Individual notifications are recorded at holding level. To contextualise the number of yearly sheep scab notifications, we used registered sheep holdings, that is, the number of holdings keeping sheep per year, as a denominator population. A holding was considered notification positive for the entire year. Therefore, subsequent notifications raised for the same holding within a year were discounted when calculating the prevalence of holdings with notifications.

Categorical data analysis

Where present the following categorical variables were counted for each year: (i) resolution status of each notification (hastened, resolved and unresolved); (ii) how each notification was resolved (negation of disease by APHA, negation of disease by private veterinary surgeon (PVS), slaughter and treatment); (iii) treatment used to resolve a notification (macrocyclic lactone [ML] or organophosphate [OP]); (iv) the active compounds chosen to treat a notification (diazinon, doramectin, ivermectin and moxidectin). Additionally, the proportion by which each level within the factor contributed to the count was calculated for each year. When assessing the proportion by which each variable differed between years, notifications with no record of the variable were omitted. The proportion by which each variable differed between years was assessed using a chi-squared test.

Spatial data

Precise coordinates were unavailable at holding level for each notification. Therefore, parish centroids were used to plot holding locations. Notifications were aggregated initially by year and then for the entire study period.

Here we were interested in the effect of county farm demographic data (Table S2) on notification counts.

TABLE 2 Total count and estimated prevalence of sheep scab notifications per year

Year	Total count of notifications	Prevalence of sheep scab notifications (%)
2014	81	0.53
2015	84	0.54
2016	93	0.61
2017	101	0.65
2018	109	0.67
2019	97	0.63

The relationship was explored using a mixed-effects negative binomial regression model (generalised linear mixed models [GLMM]). Year (2014–2019) was treated as a continuous random variable and County ($n = 33$) as a random factor. The random effect's structure included the by-County random intercept and by-County random slopes on Year. Initially, a univariate analysis was performed for each explanatory variable.

A multivariate analysis was performed, which included some farm demographic data as explanatory variables. Variables were excluded from the model if they could be used as proxy identifiers of County. Demographic variables were assessed for correlation (Pearson's correlation). Highly correlated variables were added to separate multivariate models and models were compared using a likelihood ratio test. Correlated covariates, which were included in models that explained significantly more variation, were retained. Covariates were sequentially removed from the model, and each model was compared by likelihood ratio test to the former. The most significant model was retained. All data pertaining to the county of Shetlands were removed from the analysis as sheep scab control in this region is under different legislation.

The incidence rate ratios (IRR), 95% confidence interval (CI) and p-values were assessed for all models, with p-values considered statistically significant if $p < 0.05$.

RESULTS

Temporal analysis

Five hundred and sixty-four notifications of sheep scab were recorded from 1 January 2014 to 31 December 2019, during which time the annual notification count increased (Table 2). The maximum and minimum number of notifications were observed in 2018 ($n = 109$) and 2014 ($n = 81$), respectively.

The mixed-effects Poisson regression model results showed no significant notification count differences in the five successive year comparisons (all $p = 0.3$). The omnibus effect of Year was also not significant (Likelihood-ratio [LR] chi-square = 0.966, degrees of freedom [df] = 5, $p = 0.965$). A closer inspection of the random effect parameters revealed a random variation in notification counts across counties.

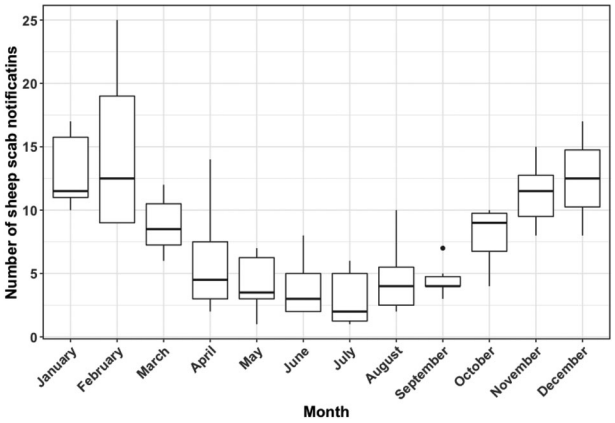

FIGURE 2 Seasonal pattern of notifications, collated during the study period (2014–2019). The horizontal line shows the median number of notifications; the box indicates the 50th percentile, the top and bottom line represent the 75th and 25th percentile, respectively, and the dots represent outliers

The full model fitted the data significantly better than a model without the by-County random intercept and associated random correlations (LR chi-square = 379.57, df = 6, $p < 0.001$). Likewise, the full model was superior to a model that did not include by-County random slopes on the effect of Year and associated random correlations (LR chi-square = 32.778, df = 20, $p = 0.036$). Therefore, apart from considerable variation across counties, there was no generalisable effect of Year on notification count.

The mean notification prevalence for the 6-year period was 0.63%. Slight variations in notification prevalence were seen between years, with a gradual increase seen from 2014 (0.53%) to 2018 (0.67%) decreasing in 2019 (0.63%).

A distinct seasonal pattern of notifications was seen (Figure 2). The reported number of sheep scab notifications were consistently high during the winter months (November–February, mean = 77 notifications/month/year) and consistently at their lowest during the summer months (May–September, mean = 24 notifications/month/year). The number of notifications reported in February showed the greatest variability per year, ranging from nine notifications reported in 2014, 2015 and 2017 to 25 notifications reported in 2018.

In total, 503 unique holdings registered one or more notifications between 2014 and 2019. Of these, 9.3% ($n = 47$) registered two or more notifications. Six repeat notifications were removed as they were within 28 days of the original notification. As such, 8.7% ($n = 44$) of holdings registered two or more notifications, while 4.6% ($n = 23$) of holdings registered repeat notifications within a calendar year (Table 3).

Categorical data analysis

The resolution status of each notification was recorded from 2015 onwards (Figure 3). Of the 483 notifications recorded, 76.2% ($n = 368$) were recorded as resolved,

TABLE 3 Number of holdings recording two or more sheep scab notifications during the study period (2014–2019) and within 12 months during the study period

Number of notifications	Number of holdings documenting more than one notification between 2014 and 2019	Number of holdings documenting more than one notification within 12 months between 2014 and 2019
2	38	21
3	2	0
4	3	2
5	1	0

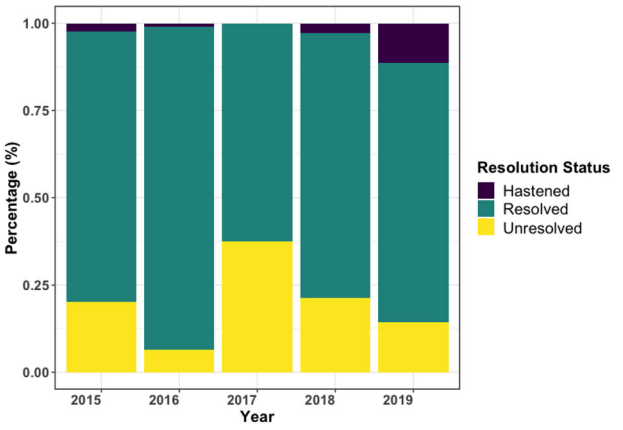

FIGURE 3 Proportional bar chart characterising the resolution status of each sheep scab notification between 2015 and 2019. Hastened: the notification has been referred to the local authority as the SS09 form was not returned within 21 days; resolved: all paperwork has been submitted correctly within an appropriate time; unresolved: relevant paperwork was not documented as being received after being hastened, and therefore, the APHA could not confirm if appropriate actions were taken to resolve the notification

20.3% ($n = 98$) were recorded as unresolved and 3.5% ($n = 17$) were recorded as hastened. The percentage of notifications recorded as unresolved consistently remained under 25% of notifications per year except in 2017, where 37.6% ($n = 38$) of notifications remained unresolved. The numbers of notifications hastened were higher in 2019 (11.3%) ($n = 11$) than in previous years, where the percentage of hastened notifications remained under 3%. The proportion of notifications in each resolution status category varied significantly between years ($p < 0.001$).

Notifications are assumed to be positive, and therefore, each notification must be resolved in accordance with this assumption. This can be done by either: (i) treating suspected infestations; (ii) slaughtering sheep suspected of being infested; (iii) proving that the disease is not present (negation of disease). In total, 413/483 notifications recorded how the notification was resolved. Of these, 1.9% ($n = 8$) of notifications recorded multiple means of resolution. Treatment was chosen by the keeper to fully or partially resolve notifications in 99% ($n = 409$) of instances. This was followed by the negation of disease by a PVS (5.8%, $n = 24$), slaughter (4.6%, $n = 19$) and negation of disease by the APHA (0.2%, $n = 1$). In 2019, a greater proportion of notifications were resolved by having a PVS perform a disease investigation ($n = 12$) when compared to earlier years ($n < 5$). The proportion by which notifications were resolved varied significantly between years ($p = 0.026$).

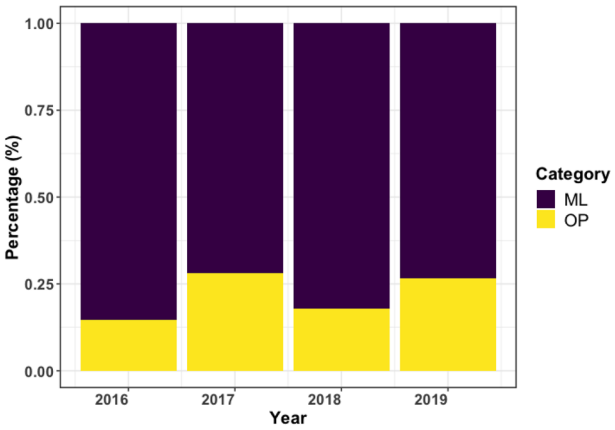

FIGURE 4 Proportional bar chart of the class of compound chosen to treat notifications of sheep scab for each year between 2016 and 2019. OP: organophosphate (diazinon); ML: macrocyclic lactones (ivermectin, doramectin or moxidectin)

TABLE 4 Percentage and number of different active macrocyclic lactone (ML) compounds ($n = 207$ treatments) used to treat notifications of sheep scab under the Sheep Scab (Scotland) Order 2010

	Active compounds		
Year	Doramectin	Ivermectin	Moxidectin
2016	48.2% ($n = 39$)	26.1% ($n = 6$)	37.8% ($n = 31$)
2017	14.7% ($n = 15$)	21.7% ($n = 5$)	9.8% ($n = 8$)
2018	26.5% ($n = 27$)	21.7% ($n = 5$)	28.0% ($n = 23$)
2019	20.6% ($n = 21$)	30.4% ($n = 7$)	24.4% ($n = 20$)

The type of treatments used to resolve notifications was recorded from 2016 onwards (Figure 4). In total, ML accounted for 79.6% ($n = 207$) of all treatments, while 20.4% ($n = 53$) of treatments were with OP. The choice of treatment used remained consistent between years ($p = 0.180$). A breakdown of the different active compounds within the ML treatment group can be seen in Table 4. Longer-acting ML products account for a greater proportion of the overall ML treatments administered, with doramectin and moxidectin accounting for 49.8% ($n = 102$) and 39.61% ($n = 82$) of ML treatments administered. Ivermectin (short-acting ML compound) accounted for only 11.1% ($n = 23$) of all treatment administrations recorded.

Spatial analysis

Figure 5a shows the total count of notifications for all 33 agricultural counties in Scotland across the study period, while Figure 5b shows the annual variation in notifications per Scottish county. Of note is the reduction in the number of sheep scab notifications over

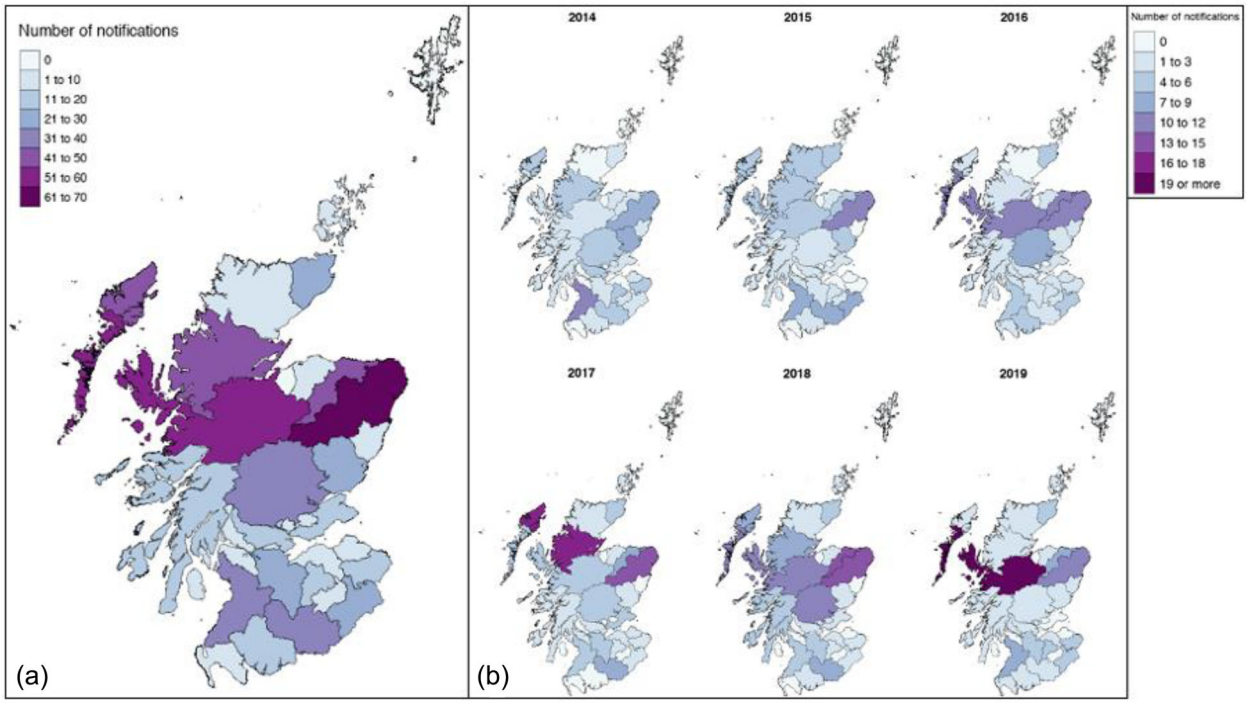

FIGURE 5 Choropleth of Scottish counties derived from the Rural and Environment Science and Analytical Services Division shapefile of parish and county boundaries. (a) The total count of sheep scab notifications reported in the study period; (b) total count of sheep scab notifications reported per county separately for each year of the study period (2014–2019)

time seen in Angus (2014: $n = 8$, 2015: $n = 6$, 2016: $n = 3$, 2017: $n = 2$, 2018: $n = 1$, 2019: $n = 1$); while in Banff (2014: $n = 2$, 2015: $n = 4$, 2016: $n = 12$, 2017: $n = 8$, 2018: $n = 13$, 2019: $n = 8$), Inverness (2014: $n = 3$, 2015: $n = 4$, 2016: $n = 10$, 2017: $n = 5$, 2018: $n = 10$, 2019: $n = 20$), Mid Lothian (2014: $n = 0$, 2015: $n = 0$, 2016: $n = 3$, 2017: $n = 2$, 2018: $n = 2$, 2019: $n = 3$) and Orkney (2014: $n = 0$, 2015: $n = 0$, 2016: $n = 0$, 2017: $n = 1$, 2018: $n = 1$, 2019: $n = 2$) the number of notifications increased over time. Both Nairn and Shetland counties recorded 0 notifications.

During the study period, the average notification prevalence was highest in Banff, Peebles and Angus, with prevalences of 1.99%, 1.59% and 1.57%, respectively. In contrast to the count data, which shows a north–north west distribution (Figure 5a,b), when prevalence was visualised, a distinct east–south east distribution to sheep scab notifications was observed (Figure S2).

Changes in within county prevalence are explored in Figure 6. The average notification prevalence in Banff was high when compared to other counties, at 1.99%. Other counties with notably high average notification prevalence were Angus, Clackmannan and Peebles, which recorded an average notification prevalence of 1.57%, 1.38% and 1.59%, respectively.

Several variables assessed within the univariate GLMM were significantly associated with the number of notifications (Table 5). Notably, as the number of holdings, the number of registered sheep holdings, the number of hectares in agricultural use and the total number of sheep within an area (County) increased, the number of notifications within those areas also significantly increased. Additionally, within univariate models, a small but significant positive association was observed between the number of holdings with access to common grazing and the number of sheep scab notifications. In addition, the proportion of hectares in common grazing in an area had a marginal effect on the number of notifications (IRR = 1.04, CI = 0.99–199, $p = 0.099$). No other variable was significantly associated with sheep scab notification count (Table 5).

No significant association was observed between variables within the multivariate model and the number of sheep scab notifications (Table S3).

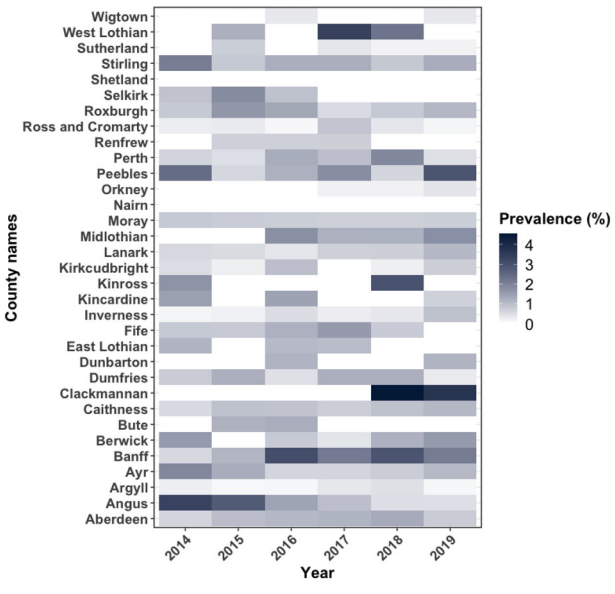

FIGURE 6 Proportion of sheep registered holdings within Scottish counties notifying the APHA of suspect sheep scab cases for each year in the study (2014–2019)

TABLE 5 Univariate negative binomial generalised linear mixed models looking at the relationship between county-level farm demographic data collected between 2014 and 2019 and the number of sheep scab notifications reported to the APHA

Variable	Units	IRR	CI	*p*-Value
Number of holdings	100 holdings	1.05	1.03–1.06	<0.001
Number of holdings registered to keep sheep	100 holdings	1.17	1.09–1.25	<0.001
Number of holdings with access to common grazing	Holdings	1.00	1.00–1.01	<0.001
Number of hectares in agricultural land	10,000 hectares	1.02	1.02–1.05	<0.001
Number of hectares in common grazing	10,000 hectares	1.07	0.98–1.16	0.115
Number of sheep	10,000 sheep	1.05	1.03–1.07	<0.001
Number of sheep per sheep registered holding	100 sheep/holding	1.01	0.90–1.14	0.848
Percentage of holdings registered to keep sheep	%	1.03	0.98–1.08	0.305
Number of holdings per hectare	Holdings/100 hectares	0.89	0.35–2.22	0.799
Number of holdings per common hectare	Holdings/100 hectares	0.62	0.17–2.30	0.474
Proportion of hectares in common grazing	%	1.04	0.99–1.99	0.099
Proportion of holdings with access to common grazing	%	1.11	0.90–1.36	0.346

Abbreviations: CI, confidence interval; IRR, incidence rate ratios.

DISCUSSION

The Sheep Scab (Scotland) Order 2010 represents an ongoing partnership between the Scottish Government and the Scottish agricultural industry, which aims to improve animal health and welfare in Scotland. In the study, extensive information from data and metadata collected between 1 January 2014 and 31 December 2019 through the Sheep Scab (Scotland) Order 2010 were analysed temporally and spatially. Through this, we assessed the impact of the continual enforcement of the Order on sheep scab notifications over time, and how notifications were spatially distributed. Based on our study, activities relating to the Order have resulted in increasingly accurate data being collected on sheep scab notifications. It has identified areas where additional improvements in data collection and scanning surveillance could further improve outcomes, positively impacting sheep scab control.

Following the deregulation of sheep scab in 1992, insufficient data have been available to track change in annual national prevalence. Reports post-deregulation suggest an initial large increase in the number of cases,[14] while recent data, from 2007 and 2008, indicate that current annual infestation prevalence in Scotland has remained between 12% and 14%.[3,16] We reported a mean annual notification prevalence of 0.61% for the years 2014–2019, which was not significantly different between years. Several factors could explain the disparity between previously reported prevalence and our results. Data collected between 2011 and 2014 show a steep decline in the number of notifications reported, from 150 to 81 notifications.[10] This suggests that the Order has impacted the number of notifications, whether due to a reduction in infestations through better control or a reduction in notifications related to either dwindling awareness of the Order or non-reporting. The latter is supported by the results from Cross et al.[18], who performed a randomised response technique study designed to encourage the divulgence of sensitive information to assess sheep scab prevalence in Wales. They concluded that the prevalence, calculated by questionnaires in 2007 and 2008,[3,16] was under-reported due to low response and social desirability bias. It is therefore unlikely that every case of sheep scab occurring since the Order's enactment was reported, as the same social bias identified within the randomised response technique study may have influenced a keeper's decision to report.

Currently, notifications are not required to be confirmed by diagnostic testing, meaning that the presence or absence of sheep scab on a holding is rarely confirmed. Consequently, notifications are a report of suspicion rather than a definitive diagnosis. The notification prevalence is therefore not a direct estimation of disease prevalence. If engagement with the Order remains constant over time, notification prevalence could represent a valuable proxy for disease prevalence, with variation in notification prevalence over time indicative of changes in disease prevalence. We believe that the rate of notification is roughly proportional to the rate of infestation. This is supported by our results which show that the number of notifications counted each month follows the expected seasonal distribution of infections,[9] with higher notification counts seen in autumn and winter.

Other authors[2] noted that previously infested holdings are more likely to experience repeated sheep scab cases. In our study, 44 (8.7%) holdings experienced two or more cases within a 6-year period, while holdings with repeat notifications within the calendar year were considerably lower ($n = 23$, 4.6%). Holdings with repeat notification within the calendar year are highlighted and summarised in an annual report, while holdings with repeat notifications occurring between years are not highlighted. A regular, broader analysis of repeat notifications over longer periods should be implemented to identify and engage with these farms to target resource allocation.

The majority of notifications (76.2%) were classified as resolved; suggesting that some aspects of the system could be improved. Evidence of improvement in the system can be seen by the increase in the number of notifications 'hastened' in 2019 (11.3%), indicating increasingly efficient processing within the APHA. Our results showed a significant difference in how each notification was resolved over time, with the number of notifications investigated by the keeper's PVS more than doubling in 2019 (n = 12, 12.4%). Both improvements occurred subsequent to the APHA updating its 'best practice' advice provided to keepers of suspect flocks via telephone conversation, summarised in Figure S3. The increasing trend in PVS involvement is undoubtedly a positive outcome as it provides an opportunity to promote the use of diagnostics such as the sheep scab blood ELISA test,[19,20] which has a higher sensitivity than the conventional skin scrape,[21] and the instigation of biosecurity protocols. This interaction has been fostered by sharing the SS10 (Figure S3) with the keeper's PVS, and should be encouraged further by ensuring that PVS are equipped with current information on best practice.

Each notification that is not refuted by diagnostic testing is assumed positive, and as such, is resolved by treatment or slaughter. Most notifications (99%) were fully or partially resolved by treatment, with most treatments (79.6%) being one of three injectable ML—doramectin, moxidectin and ivermectin. The presence of *P. ovis* mites resistant to the ML moxidectin was demonstrated in outbreaks from England and Wales in 2018,[22] and cross-resistance to all ML was later confirmed.[23] As only two classes of acaricidal compounds are licensed for treating and preventing sheep scab, their judicious use should be encouraged. For this reason, each notification should be treated once the presence of the disease has been confirmed, following the best practice principles advocated by the Sustainable Control of Parasites (SCOPS) (www.scops.org.uk). To facilitate the future mapping and tracking of mite ML resistance the collection of additional metadata should be encouraged, for example: (i) the number of animals treated; (ii) product type; (iii) dosing regimen; (iv) batch number; (v) expiry date; (vi) treatment success.

The number of notifications differed between counties at any one time. As expected, counties with more sheep and more sheep registered holdings were associated with higher notification counts. The counties with the highest number of notifications over the study period were situated in the north of Scotland, while counties with the highest notification prevalence were seen in the east. As an estimation of disease prevalence should be calculated using an appropriate denominator, we suggested correlating the number of notifications with census data (e.g. sheep holdings). The Order aims to identify, control and limit the spread of sheep scab; it may therefore be more informative to refer to the estimated prevalence of notification within a given area, based on the number of sheep or the number of registered holdings with sheep. To aid in the recognition of infestation 'hot-spots' in real-time, census data could be used to compare areas where sheep density is higher to areas with lower density. As some regions might be very densely populated (high denominator number), the estimated prevalence may not be sensitive enough to identify small but important increases in notification prevalence. In this case, calculating prevalence at a higher granularity (e.g. parish level) could overcome this issue.

Farms with access to common grazing have been associated with more outbreaks of sheep scab,[2,18,24,25] with just a few infested sheep sufficient to result in extensive outbreaks.[26] A marginal association was observed between the proportion of land in common grazing and the number of notifications seen. This may explain the high number of notifications observed in Inverness and Ross and Cromarty over the study period, both of which had a high proportion of agricultural land in common grazing. Greater emphasis on prevention may be needed in these areas.[27] For instance, Jacober et al.[28] and others proposed a test and treat strategy in Switzerland, whereby all flocks that grazed common ground were tested for *P. ovis* via ELISA before being turned to the common. Flocks testing positive were subsequently treated. Using this strategy, the proportion of seropositive flocks reduced from 5.8% to 2.1% in 3 years. Similarly, local strategies concentrating on control have been somewhat successful in Scotland before the implementation of the Order and current initiatives are exploring control on the isles of Mull and Iona.[29]

As the Order begins its second decade, it was necessary to evaluate its impact. It is clear that the Order has affected notifications in Scotland; however, there is concern over a potential lack in engagement. Understanding this will require a deeper appreciation of the barriers to engagement, including the impact of the stigma associated with sheep scab. Destigmatising may require investment in resources to increase the Order's profile within the farming press. Support structures, centred around the PVS, may be beneficial for keepers reporting a notification. These structures could include support for diagnostic testing, biosecurity advice, health planning advice and neighbour mediation. This would provide confidence when choosing to treat suspect flocks and may extend to include holdings that share boundaries with infested farms.

Despite limited resources, valuable data were gathered through the Order, the majority of which were collected in excess to the minimum required by legislation. Continued recording and periodic analysis of the data will demonstrate how changes in policy or advice given to keepers, PVS and the local authority affects observed trends. The data collected should continue to aid local approaches to sheep scab control while providing a regional picture, eventually feeding into an overall UK wide strategy. However, to fully capitalise on the current and potential benefits provided by the Order, further consideration must be given to

the type of data collected and the systems employed to capture, analyse and interpret these data. Data gathered through the Sheep Scab (Scotland) Order 2010 have the potential to provide a secure means of real-time data analysis, which will be instrumental in addressing the challenges associated with sheep scab control in Scotland.

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AUTHOR CONTRIBUTIONS

Rheinallt O. Jones collated, analysed and interpreted the data and drafted the manuscript. Valentina Busin assisted with data interpretation and contributed significantly to manuscript revision. Sibylle Mohr contributed significantly to data analysis and interpretation, and manuscript revision. SB was responsible for data acquisition and contributed significantly to data interpretation and, with Alasdair J. Nisbet, manuscript revision. Iain R. Bell and Antonia Ganser Brulisauer advised on internal APHA procedures and contributed significantly to manuscript revision. Eilidh Geddes assisted with data interpretation and contributed to manuscript revision.

CONFLICT OF INTEREST

The authors declare no conflict of interests.

ETHICS STATEMENT

The work described in this manuscript is a retrospective study of data collected by the APHA in accordance with the Sheep Scab (Scotland) Order 2010. Animals were not subjected to any interventions, and therefore, the work was not subject to animal ethics and welfare regulation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from APHA. Restrictions apply to the availability of these data, which were used under a data sharing agreement for this study. Data are available from the corresponding author with the permission of the APHA.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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