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Voluntary monitoring systems for pig health and welfare in the UK: Comparative analysis of prevalence and temporal patterns of selected non-respiratory post mortem conditions

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ABSTRACT

Collection of abattoir data related to public health is common worldwide. Standardised on-going programmes that collect information from abattoirs that inform producers about the presence and frequency of disease that are important to them rather than public health hazards are less common. The three voluntary pig health schemes, implemented in the United Kingdom, are integrated systems which capture information on different macroscopic disease conditions detected in slaughtered pigs. Many of these conditions have been associated with a reduction in performance traits and consequent increases in production costs. The schemes are the Wholesome Pigs Scotland in Scotland, the British Pig Health Scheme in England and Wales and the Pig Regen Ltd. health and welfare checks in Northern Ireland. In this study, four post mortem conditions (pericarditis, milk spots, papular dermatitis and tail damage) were surveyed and analysed over a ten and half year period, with the aim to compare the prevalence, monthly variations, and yearly trends between schemes. Liver milk spot was the most frequently recorded condition while tail damage was the least frequently observed condition. The prevalence of papular dermatitis was relatively low compared to liver milk spot and pericarditis in the three schemes. A general decreasing trend was observed for milk spots and papular dermatitis for all three schemes. The prevalence of pericarditis increased in Northern Ireland and England and Wales; while Scotland in recent years showed a decreasing trend. An increasing trend of tail damage was depicted in Scotland and Northern Ireland until 2013/2014 followed by a decline in recent years compared to that of England and Wales with a decreasing trend over the full study period. Monthly effects were more evident for milk spots and papular dermatitis. Similarity of the modus operandi of the schemes made the comparison of temporal variations and patterns in gross pathology between countries possible over time, especially between countries with similar pig production profile. This study of temporal patterns enables early detection of prevalence increases and alerts industry and researchers to investigate the reasons behind such changes. These schemes are, therefore, valuable assets for endemic disease surveillance, early warning for emerging disease and also for monitoring of welfare outcomes.

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1. Introduction

Surveillance can be defined as the systematic (continuous or repeated) measurement, collection, collation, analysis, interpretation, and timely dissemination of animal-health and welfare data from defined populations. Systematically collected data are essential for the accurate description of health-hazard occurrence and can then contribute to the planning, implementation, and evaluation of risk-mitigation actions (Hoinville et al., 2013). Endemic diseases are a particular concern to all livestock industry sectors, causing production losses and welfare issues. Surveillance plays an important role in their control: the frequency of disease (and/or welfare conditions) can be estimated; these estimates can be mon-

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itored over time and significant changes can be detected. Through early detection and informed response, surveillance helps reduce the impact of animal disease on animal production and welfare and on public health (Hoinville et al., 2013).

Coordinated industry-wide lesion scoring of pigs at slaughter has been implemented in the United Kingdom (UK) since the mid-2000 s with the development of voluntary country-specific pig health schemes; Wholesome Pigs Scotland (WPS) introduced in 2003, specialist abattoir pathology monitoring introduced in Northern Ireland in 2005 (known as Northern Ireland health and welfare checks (NI H&W)) and the British Pig Health Scheme (BPHS) also introduced in England and Wales in 2005. These schemes report the presence of different macroscopic conditions in slaughtered pigs (Sanchez-Vazquez et al., 2011). They are different from the existing inspection procedures required under food hygiene law, which place emphasis on detecting conditions with public health relevance, by utilising specialist assessors to increase sensitivity for detection of animal health related conditions. These assessors go through regular standardisation exercises to ensure consistency in scoring between assessors. Frequent feedback of benchmarked lesion prevalence data to producers helps to increase awareness of the occurrence of subclinical diseases and to assess the presence, severity and response to interventions for clinical disease (Sanchez-Vazquez et al., 2011). Such standardised data are also valuable for epidemiological studies (Jager et al., 2012; Sanchez-Vazquez et al., 2010) and also provide opportunities for animal vaccine companies and government led surveillance for emerging threats. Programmes with similar purpose have been implemented in other countries of the world (the Netherlands (Blocks et al., 1994), Scandinavian countries (Olsson et al., 2001) and New Zealand (Anonymous, 1999)).

The UK Pig Industry is one of the largest in the European Union (EU), occupying the 10th position in terms of meat production (Eurostat, 2016). According to 2015 UK Agricultural Census, there were 4.7 million total pigs (of these around 507 thousand were breeding pigs) on 11,500 pig commercial farms in UK. Around 81% of the UK pig production is concentrated in England, 12% in Northern Ireland, 7% in Scotland and less than 1% in Wales (Defra, 2016). From 2005–2015 the total number of pigs has decreased considerably for Wales (less 48%) and Scotland (less 35%) and has increased for Northern Ireland (more 40%); with little variation for England (Defra, 2016). Almost 12% of the holdings have 1000 or more animals. Over half of the pigs in England are in East Anglia and Yorkshire region. In terms of housing system, in England, around 40% of the commercial pig breeding herd are kept outdoors. Most outdoor producers provide pig arcs for shelter, with some using cabins or tents as well as or instead of arcs. Around 21% of the weaners pigs are kept outdoors. Where weaners are housed indoors, 43% are on straw with the remainder mainly on fully slatted floors. Only 3% of commercial growers (between 30 and 65 kg) and finishers (over 65 kg) are kept outdoors. The majority of pigs which are housed indoors are on straw (Defra, 2010). In Scotland around 43% of the holdings with pig older than four weeks are straw based (Anonymous, 2012).

Respiratory diseases have been identified as a major issue for pig production (Brockmeier et al., 2002). A recent study (Eze et al., 2015) described data on respiratory lesions from the UK pig health schemes, for the period between July 2005 and December 2012. The results indicated the presence of underlying respiratory disease with consequences for profitability, welfare and public health through increased reliance on antimicrobial treatments during production. However, non-respiratory disease also contributes to considerable economic losses at farm level, as well for welfare problems. Furthermore some studies have shown associations between respiratory lesions and non-respiratory lesions (e.g. association between enzootic pneumonia and pericarditis, pleurisy and pericarditis, enzootic pneumonia and papular dermatitis, pleurisy/pneumonia with tail bite lesions) (Herenda et al., 2000; Sanchez-Vazquez et al., 2012; Teixeira et al., 2016). In the current study we compared the prevalence, seasonal variations, and yearly trends for selected non-respiratory lesions (liver milk spots (MS), pericarditis (PC), papular dermatitis (PD) and tail damage). These are conditions detectable at post mortem inspection of pigs at slaughter, common to the three voluntary schemes operating in the UK countries of Northern Ireland, Scotland, and England and Wales for a ten and half year period.

Non-respiratory conditions, recorded in abattoir surveillance schemes, as listed above are believed to be associated with economic losses for the pig industry. Milk spots in the liver are evidence of recent migration of *Ascaris suum* larvae, and a cause of rejection of livers at post mortem inspection. Such infestations can also affect the growth rate and food conversion (Hale et al., 1985). A number of agents can cause papular dermatitis including insect bites, harvest mite larvae and urine scald but a very common cause is hypersensitivity to the sarcoptic mange mite (*Sarcoptes scabei* var. *suis*) (Davies et al., 1996). The presence of PD is strongly indicative of sarcoptic mange but microscopic detection of mites from skin or ear scrape samples is necessary to confirm the diagnosis. Pericarditis describes adhesions between the heart and the pericardial sac surrounding it. This non-specific condition has been associated with bacterial diseases, such as Glässer's disease (*Haemophilus parasuis*), pasteurellosis, mycoplasmosis and streptococcal infections (Buttenschon et al., 1997; Loynachan, 2012), which compromises welfare and production. Tail damage lesions, caused mainly by tail biting, may indicate stress, adverse environmental conditions and intercurrent disease among other factors (Schroder-Petersen and Simonsen, 2001). They may result in blood-borne spread of bacteria leading to septicaemia or pyaemia, resulting in total carcass rejection.

For brevity, we have used the term "England" to denote England and Wales in this paper justified by the extremely small proportion of slaughter pigs originating from Wales.

This study aims at estimating the prevalence, temporal trends and seasonality of each of these conditions in each scheme; and studies the variation in the estimates and differences in temporal patterns across schemes. The results from this study can draw the attention of respective stakeholders to conditions that may not have responded to control efforts, conditions that may be the target of future control measures and areas where further research is needed (e.g. detailed study of individual farms). We postulate that these schemes are valuable resources for epidemiological investigation and are helpful for temporal analysis and detection of differences between countries.

2. Material and methods

2.1. Data sources

The British Pig Health Scheme (BPHS) (for England and Wales), the Wholesome Pigs Scotland (WPS) (for Scotland), and the Northern Ireland (NI) surveillance scheme gather information on several pig health and welfare conditions assessed at abattoirs.

2.2. Study sample

2.2.1. WPS

The Wholesome Pig Scotland commenced in 2003 and monitors the incidence of twelve post-mortem pathologies in slaughtered pigs. Data were gathered in this scheme by independent assessors who assess every other pig on the slaughter line up to a maximum

Table 1
Description of the conditions assessed at abattoir and the scoring system used.

Lesion	Pathological lesion	Scoring system
Pericarditis	Fibrous or fibrinous adhesions of the pericardium	Binary: present or absent
Liver milk spots	Pale foci of fibrosis involving the liver parenchyma	Binary: present or absent
Papular dermatitis	Reddish papules/spots found on ventrum, neck and hams or widespread across the skin.	Four categories accounting for severity (from 0–absent to 3 – high severity)
Tail bite	Presence of old or recent tail lesions.	Binary: present or absent

of 150 per batch. See Sanchez-Vazquez et al. (2011) for details on the modus operandi of the scheme.

2.2.2. NI health and welfare checks (NI H&W)

The NI H&W assess eight conditions in selected abattoirs twice a year (June or July and November or December) since 2005. Data was not available for 2007. In 2012 the scheme changed and checks were performed three times a year (between March and May, between June and August and between October and December).

2.2.3. BPHS

The British Pig Health Scheme (BPHS) started in July 2005 with the aim of monitoring the occurrence of post-mortem gross pathology in clinically healthy pigs in England. The scheme monitors the same conditions as the WPS except snout score. A sample (up to a maximum of 50 pigs) is selected from each batch by assessing every other pig on the slaughter line. For a more detailed account of the BPHS operations see Sanchez-Vazquez et al. (Sanchez-Vazquez et al., 2011).

Data collected by these schemes between July 2005 and December 2015 (10 years and six months), from 5256 slap marks in 64,570 batches of pigs supplied to 33 abattoirs spread across the UK, were used in this investigation. In total 3,100,602 pigs were examined. Slap mark is the herd mark that is tattooed on a pig and identifies farm of origin which is a legally required official reference for each pig farm. A small number of farms may have more than one slap mark but it was not possible to identify those cases in our analysis and it was assumed that a slap mark corresponded to a farm. Table 1 describes the conditions assessed and the scoring system used for each one of them. WPS and BPHS schemes collect the data at individual level; therefore multiple conditions per animal are recorded. Papular dermatitis was transformed to a binary score. It was considered present (when having a score higher than zero) or absent (when having a score equal to zero). Therefore all the cases of this condition were included in the analysis, independently of their severity.

2.3. Modelling approach

Two approaches were used to study the temporal patterns of the conditions assessed in the three countries. The semi-parametric generalised additive model was used to obtain the smooth effects of month and trend for each condition in order to visualise the shape or pattern of these effects and compare overall prevalence estimates among countries. The generalised linear mixed model was then used to quantify these effects and compare differences between annual trend and monthly effects across countries.

2.3.1. Generalised additive model (GAM) – model 1

The semi-parametric generalized additive model (GAM) was fitted in R using the mgcv package (Wood, 2006). The model has both linear and nonparametric components. The nonparametric components are fitted as smooth function where the regression curves are estimated empirically without any pre-specified or imposed structure on the data. The mgcv package uses penalized cubic regression splines. The smoothing parameters were chosen using the Generalized Cross Validation (GCV) criterion (Wahba, 1990) such that the smoothing parameter with the lowest score is selected.

We assumed that p_{itk} is the average probability of detecting a positive condition (or prevalence rate) in month i in year t and *scheme k* such that

$A = f(month, by\ scheme)$

$B = f(time, by\ scheme)$

$C = scheme$

$Logit(P_{itk}) = \alpha + A + B + C$

The intercept α is the average log prevalence; f is a nonparametric smooth spline function which denotes the flexible functional form of the relationship between each covariate and logit of the prevalence rate of each condition. Penalized cubic regression splines were used for the two model terms and a cyclic smoother was applied to the month term. The monthly patterns were accounted for by the smooth effect of *month* while the smooth effect of *time* represents the long term trend effects, where *time* is continuous and given as $time = year + \frac{DOY}{365}$. DOY is day of the year. The differences in monthly patterns and trend across schemes were fitted as the interaction between month and scheme and between year and scheme. *Scheme* accounts for differences between the three schemes. We adjusted for overdispersion by fitting a quasibinomial distribution.

2.3.2. Generalised linear mixed effect model – model 2

Model 1 is limited by the fact that it did not account explicitly for the nested structure of the random effects in the data and may underestimate the true variance of the model parameters. Model 2 takes care of this limitation and also enables the quantification of effects.

The value p_{it} is the binomial parameter that measures the probability of observing a positive condition in month i, and year t such that

$$Logit\,(p_{it}) = \alpha + \beta cos\left(\frac{2\pi s}{P} - \theta\right) + f\,(time) + re\,(year) + re\left(abattoir/slapmark\right) 2$$

Model 2 was fitted at scheme level for each condition. Average monthly pattern is represented by the cosine function $\beta cos\left(\frac{2\pi s}{P} - \theta\right)$ where β is the amplitude of the cosine function which gives indication of extent of seasonality, θ is the horizontal phase shift which moderates the position of the curve and is estimated by transforming the cosine function. P is the period (in this case 12 months) and s is the month of the year. The trend effect is given by the polynomial function f over *time*, where *time* is as defined above. The order of the polynomial function for any given condition may differ between schemes. The determination of the form of these functions was based on the shape of the curves obtained from fitting model 1.

Model 2 adjusts for random effects due to repeated observations made on each farm and abattoirs using the term $re\left(abattoir/slapmark\right)$ which recognises the fact that farms are nested within abattoirs by adjusting for the differences in groups of farms within and between abattoirs. Slap mark random effect was adjusted to account for correlation of repeated batches from each slap mark. Also, year random effect $re\,(year)$ was used in order to allow for different intercept for each year and to capture the differences in variability of effects between years. A batch was defined as a group of pigs belonging to the same slap mark that were slaugh-

Table 2
Summary of outcomes of the surveillance schemes showing the number of pigs examined and the proportion of cases at animal level for each condition in the three schemes between July 2005 and December 2015.

Schemes	BPHS	NI H&W	WPS	All
Slap marks	4220	610	426	5256
Abattoirs	20	6	7	33
Number of batches	56,250	4481	3839	64,570
Number of Pigs	2,557,510	329,181	213,911	3,100,602
Liver milk spots	0.043	0.161	0.061	0.089
Pericarditis	0.040	0.032	0.032	0.035
Papular dermatitis	0.030	0.025	0.023	0.026
Tail damage	0.005	0.005	0.007	0.005

Legend: BPHS – British Pig Health Scheme; NI H&W – Northern Ireland health and welfare checks; WPS – Wholesome Pigs Scotland.

tered in the same abattoir on the same date. Farm random effects represent unobserved factors (e.g. herd size, production system and biosecurity levels) specific to each farm, while abattoir random effect represents factors specific to the abattoirs (e.g. assessors variability).

3. Results

3.1. Prevalence of lesions by scheme

Table 2 describes the proportion of detected positive cases for each condition between July 2005 and December 2015 in the respective schemes. Liver milk spot was the most frequently recorded condition with Northern Ireland (NI H&W) having the highest average prevalence of 16% compared to 6% and 4% in Scotland (WPS) and England (BPHS) respectively. The prevalence of pericarditis and papular dermatitis was relatively low in the three schemes with average prevalence ranging between 3% and 4%. Tail damage was the least frequently observed condition – approximately 0.5% in each of the three schemes on average within the period covered by this study.

Fig. 1 compares the yearly prevalence of lesions assessed across the three schemes. Liver milk spots was the most prevalent condition among the conditions assessed followed by pericarditis, papular dermatitis and then tail damage as shown in Fig. 1. The average prevalence of liver milk spots across the whole period was greatest in NI with average annual prevalence in the range of 13%–18% compared with 2%–6% in England and 3%–8% in Scotland over the study period. The average annual prevalence of pericarditis was highest in England (range 3–5%), compared to Scotland (range 2–5%) and Northern Ireland (range 2–4%). Average prevalence of papular dermatitis was similar for England, NI and Scotland over all with an indication that prevalence was relatively lower in Scotland versus England and NI prior to 2008 and relatively lower in NI versus England and Scotland after 2009. Average annual prevalence of tail damage lesions were generally low (range 0.2–1%) in the three schemes over the study period. However, average prevalence increased in Northern Ireland and Scotland until 2012 and 2014, respectively, while it declined in England over the study period.

3.2. Analysis of trend and monthly effects in lesion prevalence by scheme

The result obtained by fitting the GAM (model 1) to each condition for the respective schemes and extracting the additive smooth effects of trend and month are displayed in Figs. 2 and 3 respectively. Fig. 2 depicts the trends (part B of Eq. (1)) of the four conditions for the three schemes. Each row in the Figures represents a particular condition and schemes by the columns. The y-axis depicts estimates of levels of prevalence or the probability of observing a positive case for each condition.

Table 3
Odds ratio and 95% confidence interval (CI) for the estimate of scheme level differences obtained from parametric term of the GAM model 1 for all the conditions.

Conditions	Scheme (95% CI)		
	BPHS	NI H&W	WPS
Liver milk spots	1.00	4.06(3.90, 4.22)	1.34 (1.25, 1.43)
Pericarditis	1.00	0.75(0.72, 0.78)	0.75(0.72, 0.78)
Papular dermatitis	1.00	0.53(0.48, 0.58)	0.73(0.66, 0.80)
Tail damage	1.00	1.08(1.00, 1.16)	1.45(1.36, 1.55)

Legend: BPHS – British Pig Health Scheme; NI H&W Northern Ireland health and welfare checks; WPS – Wholesome Pigs Scotland; GAM – Generalised Additive Model.

3.2.1. Yearly trend

The prevalence of pericarditis rose in all three schemes from 2008 to 9 onwards. In England, the estimated prevalence increased steadily between 2005 and 2013 and declined thereafter. The annual pattern of prevalence was similar for NI and Scotland – showing a decline between 2005 and 2010 followed by an increase until 2014 when prevalence declined again in Scotland. A declining yearly trend in the prevalence of liver milk spots was observed in the three schemes, but at different rates. Rate of decline was higher in England and Scotland relative to NI. The yearly trend in the prevalence of papular dermatitis decreased in the three countries between 2005 and 2015, with fluctuations in Scotland between 2008 and 2010. The yearly trends for tail damage were similar in Scotland and Northern Ireland where prevalence steadily increased from 2008 and then declined after 2013. For England, the prevalence of tail damage cases declined through the study period.

3.2.2. Monthly pattern

The monthly patterns in prevalence (component A of Eq. (1)), averaged over the study period, for the conditions assessed are represented in Fig. 3. The dotted lines are two standard deviations from each point estimate.

The pattern of monthly influence on pericarditis prevalence was similar for the three schemes with prevalence peaking between May and July and reaching a minimum between October and January. Also, the monthly distribution of liver milk spots prevalence was similar for the three schemes with prevalence highest in September or October and lowest in April. The likelihood of observing a carcase with papular dermatitis in Scotland and NI was highest in April and decreased thereafter until it reached a minimum in September or October. Conversely in England, peak average prevalence was observed in August, falling to minimum in January or February. Prevalence of tail damage in NI was lowest in May and highest in September or October. For England prevalence was highest in February or March and lowest in August or September. In Scotland there was no observable influence of month on tail damage prevalence.

3.2.3. Quantifying the scheme effects

The last term in model 1 (component C) gave estimates of the differences in prevalence of each condition between schemes using the BPHS as baseline. Significantly fewer cases of pericarditis and papular dermatitis were observed in NI and Scotland than in England (Table 3). Liver milk spot lesions were significantly more prevalent in NI compared with the England and Scotland. The odds of finding liver milk spots in NI were more than four times that of England. Also, cases of liver milk spots were significantly higher in Scotland compared to England. Finally, odds of finding tail damage were significantly greater in Scotland than in England.

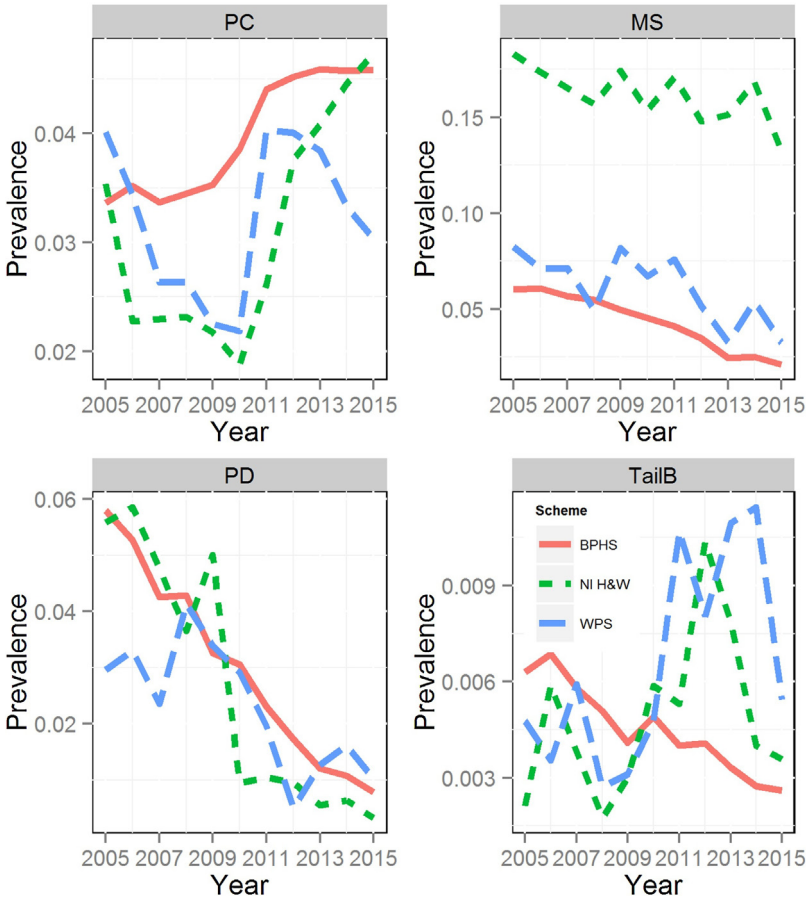

Fig. 1. Observed average annual prevalence of non-respiratory conditions (pericarditis (PC), liver milk spots (MS), papular dermatitis (PD) and tail damage (TailB)) in the three schemes (British Pig Health Scheme (BPHS), Northern Ireland health checks (NI H&W) and Wholesome Pigs Scotland (WPS)).

Table 4
Monthly effects measured by the size of the amplitude β in model 2 (expressed as odds i.e. exp (β)).

Conditions	Scheme	Monthly Effect (β)	Minimum	Maximum
Pericarditis	BPHS	1.09*	December	June
	NI H&W	1.25*	January	July
	WPS	1.09*	December	May
Liver milk spots	BPHS	1.32*	April	September
	NI H&W	1.24*	April	September/October
	WPS	1.98*	March/April	September
Papular dermatitis	BPHS	1.13*	February/March	August
	NI H&W	1.65*	September	March
	WPS	1.58*	September	March/April
Tail damage	BPHS	1.08*	March	August/September
	NI H&W	1.48*	March	September
	WPS	1.04	February/March	August/September

Legend: BPHS: British Pig Health Scheme; NI H&W: Northern Ireland health and welfare checks; WPS: Wholesome Pigs Scotland. The asterisks denote statistical significance at 5% level. The Minimum and Maximum represent monthly troughs and peaks respectively.

3.3. Quantifying seasonal effects

The extent of seasonal effect on within year prevalence for each of the conditions in the respective scheme was examined (Table 4). The effects are represented as odds ratios and the asterisks are indicative of statistical significance at 5% level of significance. The month in which troughs occurred was defined as the minimum while the maximum represented the peaks. The average monthly effects were measured by the size of the amplitude using β in model 2. The contribution of seasonality to overall prevalence for each condition varied across countries; average monthly effect could be stronger in any given scheme relative to the others for any given condition.

The time of the year where the maximum and minimum monthly effects were observed for pericarditis, liver milk spots and tail damage were similar between the three schemes. Seasonality for papular dermatitis was similar for Scotland and Northern Ireland but completely different from that observed in England.

Monthly effects were very strong for liver milk spot prevalence in all the three schemes where the effect of season could be up to 24%-98% on average (i.e. 24%-98% of change in the estimate of prevalence between the average prevalence and the maximum

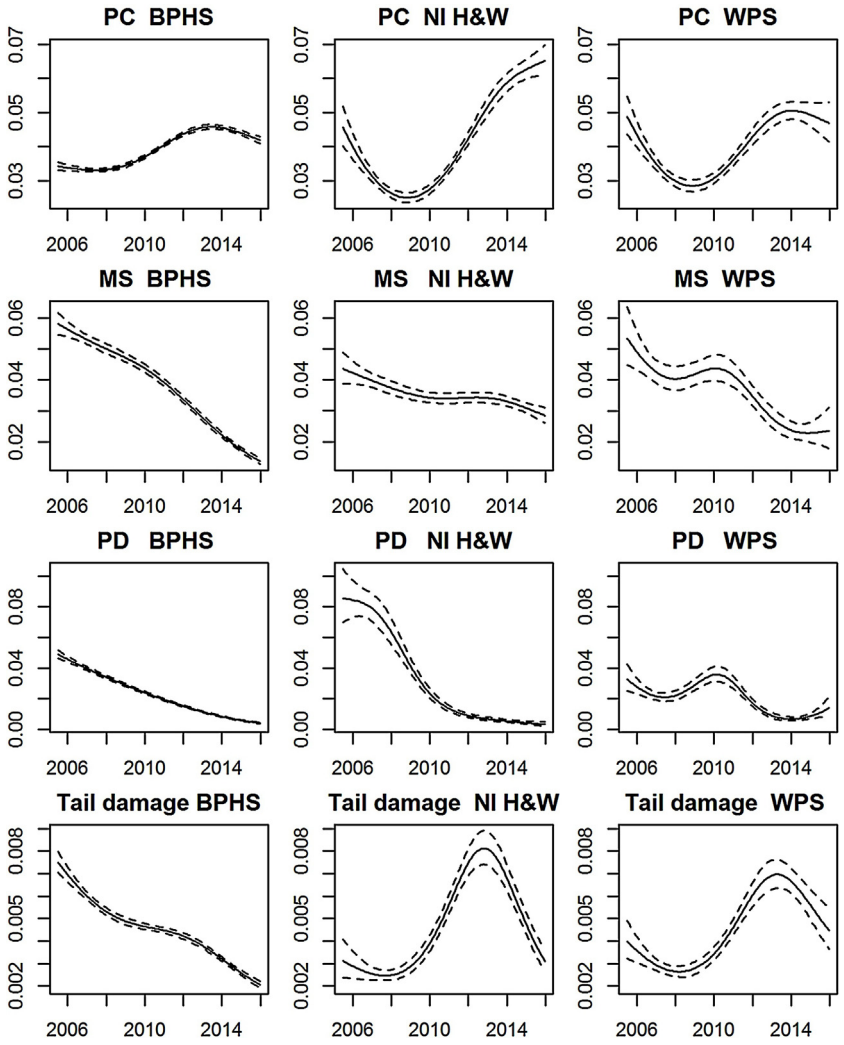

Fig. 2. Smooth trend estimates obtained by fitting model 1 to each of the four conditions (pericarditis (PC), liver milk spots (MS), papular dermatitis (PD) and tail damage) in the three schemes (British Pig Health Scheme (BPHS), Northern Ireland health checks (NI H&W) and Wholesome Pigs Scotland (WPS)). The dotted lines are 2 standard deviations from the estimated trend (solid line). The y-axis represents estimates of prevalence levels for component B of equation 1.

or the minimum). Papular dermatitis also showed high monthly effects.

As shown in Fig. 3, the estimates of monthly effects in NI especially for PD, PC and tail damage have large levels of uncertainty. This calls for caution in the interpretation of these monthly estimates. The frequency and timing of data collection in NI H&W scheme (there is not a systematic assessment of batches of pigs in all months of the year) may have impacted on these estimates.

Repeated samples were taken from the same farm (slap mark) within each abattoir in a given year. Model 2 adequately accounted for this hierarchy of variations and the estimates of the random effects are shown in Table 5. By examining the variance associated with farm, abattoir and year the relative contribution of each to the observed differences in the overall prevalence of each lesion was determined. Differences in variation as a result of the distribution of slap marks within abattoirs accounted for most of the random variations in the prevalence of all the conditions. Variation of prevalence rates between abattoirs is not as important as that of the groupings of farm prevalence within abattoirs, except for tail damage in England. Also, the year random effects were less influential on the variability of average prevalence compared with the nested effects of abattoir and farms, except for papular dermatitis in NI.

Table 5
Summary of Random Effects of year, abattoir and nested farms in abattoirs (Farm) obtained from model 2. The percentage contribution to the total variation is in brackets.

Conditions	Scheme	Year	Abattoir	Farm
Pericarditis	BPHS	0.08 (3)	0.39 (17)	1.88 (80)
	NI H&W	0.81 (29)	0.00 (0)	2.0 (71)
	WPS	0.10 (10)	0.20 (20)	0.71 (70)
Liver milk spots	BPHS	0.10 (3)	1.11 (32)	2.29 (65)
	NI H&W	0.24 (9)	0.54 (19)	1.99 (72)
	WPS	1.43 (22)	1.22 (19)	3.86 (59)
Papular dermatitis	BPHS	0.87 (12)	1.61 (22)	4.76 (66)
	NI H&W	5.91 (65)	0.50 (5)	2.75 (30)
	WPS	2.05 (17)	3.48 (29)	6.35 (53)
Tail damage	BPHS	5.55 (25)	12.29 (55)	4.56 (20)
	NI H&W	3.71 (36)	1.95 (19)	4.68 (45)
	WPS	0.33 (14)	0.48 (21)	1.53 (65)

Legend: BPHS: British Pig Health Scheme; NI H&W: Northern Ireland health and welfare checks; WPS: Wholesome Pigs Scotland.

4. Discussion

Standardised voluntary abattoir pathology monitoring programmes offer significant value to producers, veterinarians, animal

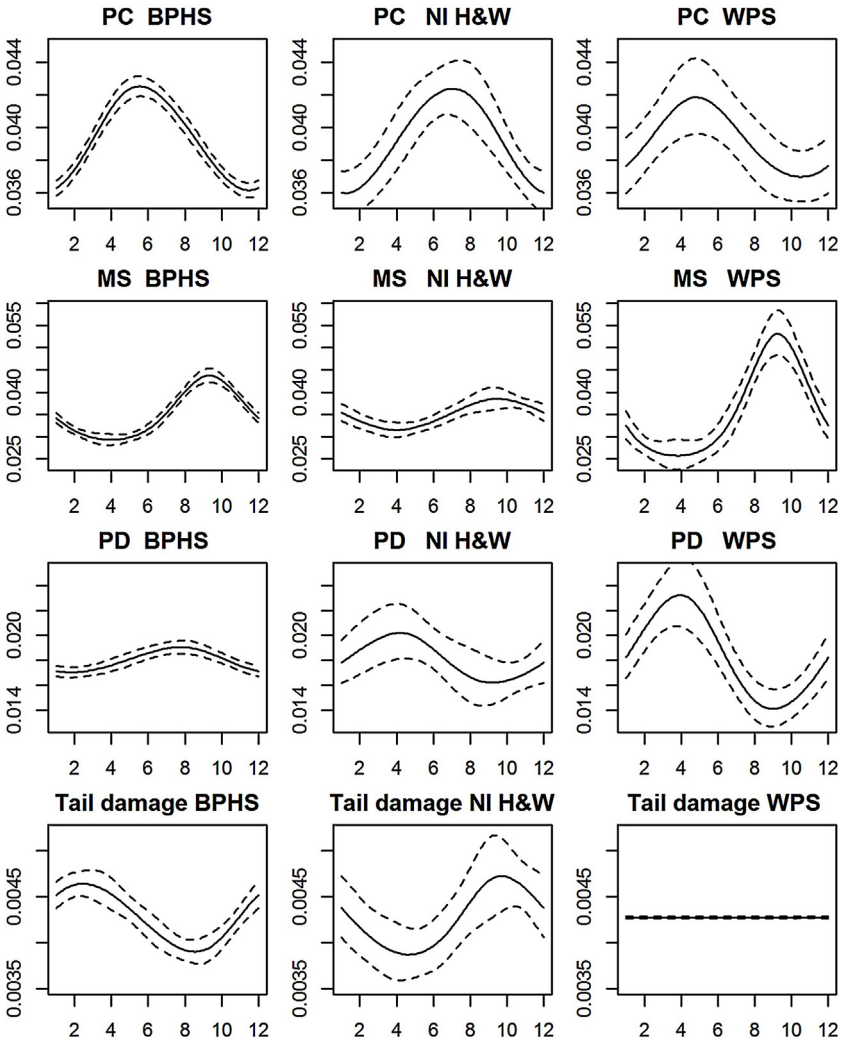

Fig. 3. Smooth estimates of seasonal patterns obtained by fitting model 1 to each of the four conditions (pericarditis (PC), liver milk spots (MS), papular dermatitis (PD), tail damage) in the three schemes (British Pig Health Scheme (BPHS), Northern Ireland health checks (NI H&W) and Wholesome Pigs Scotland (WPS)). The dotted lines are two standard deviations from the estimated trend (solid line). The y-axis represents estimates of prevalence levels. The x-axis represents the months of the year (1–January to 12–December).

vaccine companies and national surveillance programmes. However, the greatest value is their contribution to research into the epidemiology, risk factors and new management strategies for significant diseases, through integration with other data sources (e.g. farm data). The analysis and comparison of data collected from parallel monitoring programmes in Northern Ireland, Scotland and England over a ten and half year period demonstrated the value of such monitoring programmes in identifying trends in the emergence or disappearance of specific lesions, and given appropriate statistical analyses in identifying monthly and country-specific effects that might underpin the epidemiology of these lesions. This focuses researchers on the most appropriate areas for further research into each disease complex.

As an example, a steady increase in prevalence of pericarditis was observed in England since the beginning of the scheme until 2013 and in the last two years of the study it remained high. The prevalence of pericarditis also increased recently in Northern Ireland but, in this country, this increase followed a previous decline. In Scotland the prevalence has fluctuated but recently it has been decreasing. Although a number of agents can cause pericarditis, it has been suggested as a common complication of enzootic pneumonia (EP) due to secondary invasion with *E. coli.* (Herenda et al., 2000). Indeed, it was showed in a previous study (Eze et al., 2015) that the prevalence of EP-like lesions has increased significantly in England and Scotland from 2005 to 2012. However, the marked converse decline in EP-like lesions in NI in that same study, alongside increasing pericarditis prevalence sheds uncertainty over the relationship between EP-like lesions and pericarditis in NI. Furthermore none of the pericarditis prevalence monthly peaks (May to July) coincided with the seasonal patterns described for EP-like lesions in the respective countries (EP-like lesions peaked in winter (December to February)). Taken together these observations indicate the requirement for re-evaluation of the causal factors of pericarditis and presumed relationship with EP-like lesions.

The annual pattern of the prevalence of milk spots, caused by *Ascaris suis* larval migration, was similar across the three schemes with a general decrease in prevalence over the years. The monthly pattern was also similar in the three schemes with peaks in September and troughs in April on average. This parasite usually causes no overt clinical signs, but it is associated with economic consequences due to the condemnation of livers at abattoir and also due to poor production performance at farm level (Hale et al., 1985). Milks spots only persist for approximately one month post-migration of the larvae, making the lesion a sensitive indicator of recent exposure to the parasite (Stewart and Hoyt, 2006). It was described that migratory larva could cause lung damage

and in this way increase the EP-like lesions prevalence (Taylor, 1995). The decrease in the prevalence over time suggests that the anthelminthic programmes were successful in UK, although it is noticeable that NI has a higher prevalence of liver milk spots over time compared to Scotland and England. Indeed NI has four times higher odds of having animals affected by liver milk spots compared to England. Further investigations, based on these evidence-based observations, might explore whether there are explanatory differences in the uptake of anthelmintic use, or in cleaning and disinfection practices on Northern Ireland farms compared to those in Scotland or England.

The prevalence of pigs with papular dermatitis decreased in the three schemes during the study period. However, prevalence declined steadily in England and Northern Ireland but fluctuated in Scotland. The monthly pattern for papular dermatitis was similar for Northern Ireland and Scotland (peaking in April), but in direct contrast to the observed pattern in England (peaking in August). Papular dermatitis is considered a proxy measure of sarcoptic mange (Davies et al., 1996). Differences in the monthly prevalence of lesions between the different countries may be influenced by regional differences in predominance of types of finishing accommodation. In naturally ventilated straw-based finishing environments (Damriyasa et al., 2004), predominating in the South of England, survival of *Sarcoptes scabiei var. suis* eggs and larvae may be greater during the warmer summer months. Mange has severe economic consequences for pig production and over time (Davies, 1995) producers have put in place measures to eliminate it from their herds (BPEX, 2011). These efforts seem to have yielded positive results as indicated by the decreasing yearly trends. In addition, other biting insects may be significant at country level and resulted in over-estimation of the true prevalence of papular dermatitis.

Tail damage lesions showed a general decrease over time in England, while in Scotland and NI, a converse pattern with increasing prevalence until 2013 followed by a decrease. Even though for the three schemes the prevalence of animals affected was very low (less than 1%) it is important to note that tail biting is the main cause of tail damage and this is considered a welfare problem (EFSA, 2007). Due to its nature, it is difficult to assess at abattoir if the problem happened at farm level or at transport/lairage level. This is because the schemes reported any type of tail damage and do not record if it is recent or old. However, it contributes to the monitoring of welfare. These observations point the way towards evidence based investigations that could build on this data to compare environmental and managemental differences between the three countries, and how this might inform control plans to result in positive outcomes. For example, differences in floor types, space, and feeder access might be of relevance (Schroder-Petersen and Simonsen, 2001). Interpretation of BPHS results requires some caution as in some abattoirs, which are part of this scheme; it is difficult to accurately assess tail damage due to the rapid speed of the lines and the position of the schemes' assessors in the lines. This is highlighted by the fact that in model 2, for this scheme, the abattoir random effects was responsible for 55% of the random variation in the model; suggesting differences between abattoirs.

These voluntary schemes do not collect information regarding farm management practices that might explain some of the trends observed. However, during this time period (2005–2015) the UK herd has seen small variation in terms of absolute numbers of pigs (less 2.5% of the total pigs), mainly due to a decrease in the number of breeding animals (less 8.4% breeding pigs) (Defra, 2016). There has been little change to the housing systems within England from 2006 to 2009 (year with the last reportable data) and the same is probably true for the rest of UK: slight increase of breeding animals and weaners kept outdoors, a decrease of the number of growers kept outdoors, an increase of growers and finishing pigs that are kept in straw based systems (Defra, 2010). There are no data on the variation in pig housing for other countries. This increase in straw based system could pose an additional risk to the spread of *Ascaris suum* and *Sarcoptes scabiei*, however this study shows that the prevalence of the milk spots and papular dermatitis (lesions proxies for these agents) decreased over time, reinforcing the suggestion that herd health plans to tackle these agents (e.g. anthelminthic programmes) have been overall successful in UK. Within such monitoring schemes, with lesions of generally low prevalence, significant differences or changes may be observed due to changes in lesion prevalence in pigs from a very small number of units or even from individual large units. The causes of such changes may not be identifiable without detailed study of individual farms, and may not reflect the situation in the wider industry.

The prevalence of milk spots and papular dermatitis at UK level (8.9% and 2.6%, respectively) seem to be lower than what has been reported in New Zealand (9.2% and 3.6%, respectively) (Neumann et al., 2014), indicating a better control of these lesions. However the time periods for these comparisons do not completely overlap, therefore these differences should be interpreted with caution.

The estimates of monthly effects provided an insight of extent of seasonality that affects average annual prevalence. Overall the effects were low for the BPHS. In contrast Northern Ireland showed the highest monthly effects. However the frequency and timing of data collection in that country may have impacted on these estimates, especially for specific months (January, February and September) where few data collections occurred over the study period.

Data from this study provide insight into the relative contribution of the farm versus the abattoir and the year in the variation of the lesions prevalence. Lesions easy to identify at slaughter such as milk spots and pericarditis were strongly influenced by farm factors, as observed in other studies (Neumann et al., 2014). While lesions such as tail damage were influenced by the abattoir, especially for the BPHS, indicating, as suggested above, that logistic problems may influence how they are assessed. If these schemes are to continue these effects should be looked at.

These voluntary monitoring schemes are not without deficiencies. The frequency of monitoring, the number of animals being monitored, not covering 100% of the pig population and the fact that few lesions being recorded are pathognomonic for a particular disease thus limiting the specificity of the surveillance activity, are some of the concerns associated with them (Stark and Nevel, 2009). One could argue that statutory recording of carcass lesions at the abattoir (known as meat inspection) could provide similar data with the greater coverage (cover 100% of the slaughtered pigs); however a recent study (Correia-Gomes et al., 2016) compared meat inspection in one of the voluntary schemes (BPHS) and suggested that, although there is potential to use meat inspection data as a component of a surveillance system to monitor temporal trends and regional differences of chosen indicators at population level, at producer level and for low prevalence conditions it needs further improvement. The authors concluded that a number of issues (e.g. the recording of correct slap mark for each pig and the double counting of animals with multiple conditions, standardisation of meat hygiene inspectors in terms of assessment and recording of conditions) still need to be addressed in order to provide the pig industry with the confidence to base their decisions on routine meat inspection data (Correia-Gomes et al., 2016). These results lead us to suggest that the voluntary schemes are still valuable tools for the UK pig sector, for integrated and non-integrated farms.

The outputs at country level have significant value as indicators of endemic and emerging disease trends, and for producers and herd veterinarians in planning and evaluating herd health control

programmes, and welfare outcomes when comparing individual farm results to the country average.

5. Conclusions

This study highlighted the comparative value of the data available from ongoing abattoir pathology monitoring schemes in UK. Similarity of schemes allows for trend comparisons to be made between countries over time in gross pathology, especially between countries with a similar pig production profile. This enables early detection of increases in prevalence which, in turn, promotes industry and researchers to investigate the reasons behind any changes. These schemes provide national benchmarks, and are valuable assets for endemic disease surveillance, emerging disease early warning, and also for welfare outcomes monitoring. The use of these advanced statistical methods across several datasets allowed us to pinpoint farm, abattoir and national effects, which in the future will help refine research questions.

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Conflict of interest

The authors declare that they are not in a situation of conflicting interests.

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