Epidemiological Investigations Utilizing Industry Abattoir Data
- a Study in Finishing Pigs

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Epidemiological investigations utilizing industry abattoir data – a study in finishing pigs

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Epidemiological investigations utilizing industry abattoir data - a study in finishing pigs

Epidemiologisch onderzoek op basis van slachthuisinformatie
- een studie in vleesvarkens
(met een samenvatting in het Nederlands)

Investigaciones epidemiológicas utilizando datos de matadero de la industria
- Un estudio en cerdos de engorde
(con un resumen en castellano)

Recherches épidémiologiques utilisant les données des abattoirs de l'industrie
- Une étude chez le porc d'engraissement
(avec un résumé en français)

Proefschrift
ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof. dr. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op woensdag 10 juli 2013 des middags te 2.30 uur

door

Manuel José Sánchez Vázquez

geboren op 4 augustus 1976 te Madrid, Spanje

Promotoren: **Prof.dr. M. Nielen**
Prof. G.J. Gunn

Co-promotor: **Dr. F.I. Lewis**

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and

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1 General Introduction

1.1 Background on disease surveillance

Disease surveillance is a first step to understand the animal health situation of a country (OIE, 2012). The surveillance strategy is subjected to many factors, including the type of disease (e.g. endemic, emerging, international threat, etc.), the nature of the animal population involved (professional/commercial farming, hobby/small units, companion animals, wildlife, etc.), the resources available (official veterinary capacities, number and distribution of veterinarians, gross indigenous production, etc.), relevance of the livestock industry within the country (including the importance of animals and animal product trade), and so on. Preferably, veterinary authorities responsible for the design of the surveillance strategy should aim to incorporate and collate as many sources of animal health information as possible (e.g. official and private laboratories, abattoirs, farmers, veterinarians in practices, research projects, etc.). While governments are normally behind the surveillance and control of exotic threats, industry takes the lead on activities associates with endemic diseases (More, 2008).

Improving animal health surveillance and the identification of simple and reliable indicators for animal health are priorities in the current agenda of the European Union on animal health strategy (European Commission, 2007). Additionally, as a consequence of the 2007–2012 global financial crisis, there is an on-going review on the administration of official resources (Ambler et al., 2010) and cuts on funding have been applied to different subjects, impacting on the three main axes that support animal disease control: research, governmental animal disease surveillance activities and subsidies to private initiatives.

1.2 Sources for abattoir health monitoring

In the current scenario of limited funding, there is an opportunity to review the disease surveillance strategies to make them more cost-effective and to put in value existing data sources. For this purpose, abattoir inspections might offer a useful tool for animal health monitoring and as a source of data for epidemiological investigation. A good example of collective use of abattoir health data are the health schemes. These initiatives provide feed-back of results from the abattoir inspections to the participating producers and their herd veterinarians, contributing to increase their awareness of the occurrence of these diseases in their herds. The Danish pig health scheme (Willeberg et al., 1984) was an earlier attempt at establishing a structured operating system to standardise the collection of pig abattoir inspections data and to utilise them to improve the health of the herds of origin. In the Netherlands, an integrated quality control system to record and report the abattoir post-mortem information was developed contemporaneously to the Danish scheme (Elbers et al., 1992). Other European initiatives consisting of pig abattoir databanks have been utilized in Scandinavia and Northern Ireland (Willeberg et al., 1984; Goodall et al., 1993). The health schemes are the counterpoint to the official abattoir meat inspections, implemented by the governments worldwide to maintain food hygiene standards and to ensure food safety in meat through post-mortem inspections. The official system normally lacks of infrastructure to provide feed-back to veterinarians and producers and is essentially a public health tool.

Over the past decade in Great Britain, the pig industry developed health schemes to monitor the occurrence of gross pathology in pigs at slaughter. These initiatives consist of Wholesome Pigs Scotland (WPS) for Scotland and the BPEX Pig Health Scheme (BPHS) for England and Wales. These schemes record the presence of various pathologies detected by means of detailed post-mortem inspection (in the pluck and on the skin) of clinically healthy pigs submitted for slaughter and destined to enter the human food chain. These pathologies are associated with a reduction in performance traits (e.g. feed conversion rate, daily weight gain) (Stewart and Hale, 1988; Straw et al., 1989; Sorensen et al., 2006) or are indicators of the presence of welfare problems in affected herds (Taylor et al., 2010).

1.3 Studied abattoir pathologies

The two lesions that have remained most prevalent since the introduction of the health schemes have been enzootic pneumonia-like (EP-like) lesions and pleurisy. It has been reported that environmental factors and management practices play an important role in the development of respiratory conditions, together with the presence of the infectious agents (Done, 1991; Stärk, 2000). The high prevalence of EP-like lesions and pleurisy at slaughter is a constant reminder of the importance of respiratory disorders in pig production and of the potential financial losses to the industry incurred by such disorders. The identification of risk factors that influence the occurrence of these pathologies and of their temporal pattern could help the pig industry to establish more effective preventive and control strategies.

Ascariosis (*Ascaris suum* infestation) is the most important internal macro-parasitism present worldwide in farmed pigs (Stewart and Hoyt, 2006). Ascariosis can be detected in slaughtered pigs by the presence of milk spots – whitish healing foci occurring in the liver stroma due to migrating *A. suum* larvae (Stalker and Hayes, 2007); and in this way is monitored by the British pig health schemes. A number of economic losses have been attributed to it, including depression of the growth rate (Stewart et al., 1996) associated with a decrease in the feed conversion rate (Stewart and Hale, 1988). In abattoirs, the presence of milk spots represents considerable losses due to offal condemnations (Brown et al., 2007). Housing conditions (e.g. flooring type) and management practices (e.g. cleaning and disinfection procedures; type of feeding) play an important role in the development of *A. suum* (Roepstorff and Nansen, 1994; Roepstorff and Jorsal, 1990; Petkevicius et al., 1997). Also, seasonal fluctuations in the parasite development and in the subsequent presence of milk spots have been reported (Stevenson, 1979; Goodall et al., 1991; Wagner and Polley; 1999). There have been, however, insufficient recent studies to investigate those factors that influence the prevalence and distribution (both temporal and geographical) of the parasite within the current systems of production used by the British pig industry.

1.4 Abattoir data for epidemiological studies

Previous studies have used abattoir reports to perform epidemiology-based analyses to investigate risk factors for the presence of different pig pathologies (Hurnik et al., 1994; Stärk et al., 1998; Clevelance-Nielsen et al., 2002; Enoe et al. 2002; Ostanello et al., 2007; Stevenson, 1979; Goodall et al., 1991; Wagner and Polley; 1999). The utilization of abattoir data allows large scale epidemiological studies that otherwise would necessitate significant budgetary and logistic resources as these lesions cannot easily be detected in the live animal. This approach, however, has not been widely exploited in Great Britain. The activities of the British pig health schemes offer animal health data obtained from consistent monitoring which is suitable for epidemiological studies.

2 Aims and objectives

The objective of this thesis was to bring together existing information from British pig industry on animal health abattoir data to perform epidemiological analyses aimed at identifying disease determinants for three major abattoir detected pig pathologies. The pig pathologies investigated were EP-like lesions, pleurisy and milk spot liver (for ascariosis), sourcing the information from the British pig health schemes. This thesis was accomplished through six Objectives (presented in their respective Chapters):

1. Describing the British pig health schemes and exploring their possibilities as integrated systems for large-scale pig abattoir lesion monitoring
2. Identification of factors influencing the occurrence of enzootic pneumonia-like lesions and pleurisy in slaughtered pigs
3. Identification of factors influencing the occurrence of milk spot livers in slaughtered pigs
4. Using seasonal-trend decomposition based on loess (STL) to explore temporal patterns of pneumonic lesions in finishing pigs slaughtered in England, 2005-2011

5. Time-series analysis for *A. suum* related liver pathologies in English abattoirs, 2005-2010
6. Identifying co-dependencies between pig pathologies using Bayesian network structure discovery.

The statistical methodology was an important component in this thesis, aiming to utilise, for each piece of research, the best tool – to produce robust results but also to be able to extract the information available in the data. Thus, several multivariable models have been assessed including those to account for data clustering such as beta binomial and mixed-effects models. Additionally, it utilised and described the application to veterinary data of techniques barely used until now on this field such as seasonal-trend decomposition based on loess (STL) for time series analyses and the use of Bayesian network structure discovery to investigate multiple co-dependencies among a domain of variables.

This thesis also intended to produce meaningful outputs that could directly inform the industry, providing feed-back on the utilization of the data kept and provided by them. A continuous interaction was maintained with different stakeholders of the industry (including abattoir representatives, field veterinarians and consultant from pharmaceutical companies) and expert from academic and governmental bodies.

In the summarizing discussion, the findings and outcomes learned from each piece of research are put in a broader perspective and taking into account socioeconomic aspects behind its funding (government versus industry).

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Chapter II

The British pig health schemes: integrated systems for large-scale pig abattoir lesion monitoring

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Manuel J. Sanchez-Vazquez; W. David Strachan; Derek Armstrong; Mirjam Nielen; George J. Gunn

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Abstract

Pig health schemes based on abattoir inspections provide an integrated system to optimise the post-mortem detection and the reporting of pathological lesions. In Great Britain, two initiatives have been implemented by the pig industry – Wholesome Pigs Scotland (WPS) and BPEX Pig Health Scheme (BPHS). These schemes record the presence of a range of pathological lesions detected by means of detailed inspection of the pluck and the skin of the slaughtered pigs. The lesions are those associated with a reduction in performance traits or are indicators of animal welfare problems. This paper aims to provide an overview of the objectives behind the British pig health schemes and their activities, presenting WPS vis-à-vis BPHS on five main operational topics: the lesions monitored; the administration of the schemes; flow of the information; inspection strategies; and the major idiosyncratic characteristics of the schemes. These initiatives inform individual producers and their veterinarians of the occurrence of pathological conditions affecting their pig herds. Additionally, they offer the added-value of providing nation-wide disease monitoring information and have the potential to be a useful surveillance tool for emerging and enzootic conditions.

1 Introduction

A coordinated industry-wide initiative to monitor the occurrence of gross pathology in pigs at slaughter was implemented in Great Britain with the development of two health schemes; Wholesome Pigs Scotland (WPS) started in 2003 and the BPEX Pig Health Scheme (BPHS) in 2005. These schemes record the presence of various pathologies detected by means of detailed post-mortem inspection (in the pluck and on the skin) of clinically healthy pigs submitted for slaughter and destined to enter the human food chain. The pathologies monitored are usually associated with a reduction in performance of those pigs presented with the lesions or are potential indicators of the presence of welfare problems in the herds. The health schemes provide feed-back of results from the abattoir inspections to the participating producers and their herd veterinarians aiding an increase in their awareness of the occurrence of these diseases in their herds. The Danish pig health scheme (Willeberg et al, 1984) was an earlier attempt at establishing a structured operating system to standardise the collection of pig abattoir inspections data and to utilise them to improve the health of the herds of origin. In the Netherlands, an integrated quality control system to record and report the abattoir post-mortem information was developed contemporaneously to the Danish scheme (Elbers et al, 1992). Other European initiatives consisting of pig abattoir databanks have been utilized in Scandinavia and Northern Ireland (Willeberg et al, 1984; Goodall et al, 1993).

Abattoir inspections are a useful tool for pig health monitoring and have also been used as a data source for epidemiological studies. The presence of lung lesions in slaughter pigs (e.g. pneumonia and pleurisy) has been used to investigate risk factors influencing respiratory conditions (Hurnik et al, 1994; Stark et al, 1998; Enoe et al, 2002; Cleveland-Nielsen et al, 2002; Ostanello et al, 2007; Fraile et al, 2010; Sanchez-Vazquez et al, 2010a; Meyns et al, 2011). Milk spot liver post mortem findings have contributed to the investigation of the epidemiological and husbandry aspects of *Ascaris suum* (Bernardo et al, 1990; Goodall et al, 1991; Boes et al, 2010; Sanchez-Vazquez et al, 2010b).

Improving animal health surveillance and the identification of simple and reliable indicators of animal health are priorities in the current agenda of the European Union on animal health strategy (European Commission, 2007). The British pig health schemes, as unique initiatives of their kind, could be used as a model by other industries. Records from the health schemes are in the process of being incorporated into the national surveillance systems as part of Rapid Analysis and Detection of Animal-related Risks (RADAR) (Defra, 2011). The systems provide high quality data that offer opportunities for analysis in animal health and production research projects.

This paper describes the structure, working process and goals of the British pig health scheme initiatives and outlines the similarities and differences between WPS and BPHS. This paper is intended as a reference to inform current or potential stakeholders involved with such health schemes and to promote awareness of these initiatives.

2 Material and Methods

The combined experience of the authors, either involved in implementation of the health schemes or providing administrative and analytical support, along with an external view from an epidemiological perspective, is used to review the internal protocols of WPS and BPHS and describe their characteristics. The main topics presented are the lesions monitored, the administration of the schemes, the flow of the information, the inspection strategies, and the major unique characteristics of the schemes. Abattoir data for 2010 was accessed through WPS and BPHS to calculate descriptive figures (e.g. number of pigs assessed, number of herds, etc.) that serve as indicators of the schemes' most recent activity.

3 Results

3.1 The lesions

The same 12 gross pathological lesions are reported by both health schemes: Enzootic-pneumonia-like lesions, pleurisy, pleuropneumonic lesions, liver milk spots, hepatic scarring, papular dermatitis, tail damage, peritonitis, pericarditis, pyaemic lung lesions, lung abscesses and viral-like pneumonia. All the lesions are assessed and recorded independently, and multiple lesions can therefore be recorded for an individual pig. These 12 pathologies were chosen as they can be readily identified in the inspections of the pluck and by examining the skin and tail of the pig carcasses. They are associated with reducing pig production efficiency and/or with animal welfare problems. The inspection of additional lesions in other organs/body parts (e.g. nephritis, arthritis) would have been more time consuming and not feasible due to the abattoir line speed. Nasal turbinate atrophy is assessed in the WPS scheme when the condition is known to be a problem in the inspected herd.

The classification of the pathologies is per individual pig carcass and each pathology uses different scoring systems. EP-like lesion scores, pleurisy and papular dermatitis are scored in gradients that represent the severity or extent of the lesions. All the other lesions are scored in a binary form recording just presence or absence of the lesions. A more detailed description is presented in Tables 1 and 2.

Table 1. Summary of the gross pathology description of respiratory conditions studied and their most typical cause.

Lesion	Pathological lesion	Main Causal agent	Scoring system
Enzootic pneumonia-like lesions	A red-tan-grey discoloration, collapse, and rubbery firmness affecting cranioventral regions of the lungs in a lobular pattern.	*Mycoplasma hyopneumoniae* is the usual causal infectious agent (Caswell and Williams, 2007).	Represent the approximate percentage of lung with consolidation. Scale from 0 to 55 in 5 steps.
Pleurisy (or pleuritis)	Fibrous/fibrinous pleural adhesions.	Can be associated with *Actinobacillus pleuropneumoniae*, *Pasteurella* spp, *Mycoplasma hyorhinis.*, swine influenza and *Haemophilus parasuis* (Enoe et al, 2002)	Three categories. For WPS (and for BPHS until June 2008), the three categories represent severity of the lesion with baseline being absence. For BPHS (from July 2008), 1 for adhesions between lung lobes only, 2 for adhesions involving the visceral pleura and the parietal pleura and 0 for absence.
Pleuropneumonia-like lesion Either acute or chronic	Focal areas of bronchopneumonia with overlying pleurisy usually affecting the middle or caudal lung lobes.	Often associated with *A. pleuropneumoniae* infection (Caswell and Williams, 2007).	Binary, present or absent.
Viral-like pneumonia	Lobular pattern with consolidation, rubbery texture or congestion are typical of porcine reproductive respiratory virus and porcine circovirus type 2. Atelectasis/collapsed areas are observed with swine influenza.	Can be associated with porcine reproductive respiratory virus, porcine circovirus type 2 infection and swine influenza (Caswell and Williams, 2007).	Binary, present or absent.
Abscess	Localized abscesses within lung.	Various secondary pathogens including *Arcanobacterium pyogenes* (Huey, 1996)	Binary, present or absent.
Pyaemia	Multiple small abscess detected in the lung parenchyma.	Usually associated with a pyaemic spread of infection from other focus. *A. pyogenes* is a frequent cause (Huey, 1996).	Binary, present or absent.
Snout Score	Atrophy of the ventral and dorsal nasal tubinates, which is implicated by the presence of more severe turbinate atrophy.	Toxigenic *Pasteurella multocida* is the main cause of progressive atrophic rhinitis (de Jong, 2006).	A sample of around 20 snouts per batch scored 0-5 according to presence and severity of atrophy.

Table 2. Summary of the gross pathology description of non-respiratory conditions studied and their most typical cause.

Lesion	Pathological lesion	Main Causal agent	Scoring system
Liver Milk Spots	Whitish foci of fibrosis involving the liver parenchyma.	*Ascaris suum* larvae are immobilized by the host's inflammatory reaction (Stalker and Hayes, 2007).	Binary, present or absent.
Hepatic scarring	Mild fibrotic lesions affecting the capsule of Glisson, with no liver parenchyma alteration.	Possibly associated with healed *Ascaris suum* lesions.	Binary, present or absent.
Papular dermatitis	Reddish papules/nodules found on ventrum, neck and hams or widespread across the skin, depending on the severity.	This lesion is potentially associated with Sarcoptic mange (Cargill et al, 1997).	Four categories: accounting for severity and distribution of the skin lesions, baseline being absence.
Tail damage	Presence of old or recent tail lesions.	Typically associated with tail biting (Taylor et al, 2010).	Binary, present or absent.
Peritonitis	Fibrous/fibrinous/ fibrinopurulent lesions.	Associated with various bacteria such as *Arcanobacterium pyogenes* and *Escherichia coli*. Serofibrinous lesions associated with *Haemophilus parasuis* (Glässer's disease) and *Streptococcus suis*. (Reams et al, 1994; Brown et al, 2007)	Binary, present or absent.
Pericarditis	Fibrous/fibrinous/ fibrinopurulent adhesions of the pericardium.	Non-specific condition that could be associated with bacterial diseases, e.g. Glässer's diseases and pasteurellosis (Grant Maxie and Robinson, 2007).	Binary, present or absent

3.2 Administration of the health schemes

The health schemes are implemented and managed by organizations funded through a levy collected for each slaughtered pig. WPS is administered with the support from Quality Meat Scotland (QMS, 2011). BPHS is managed by the BPEX, a division of the agricultural and Horticultural Development Board (BPEX, 2010). The administrators coordinate the stakeholders participating in the schemes, manage the budget, carry out knowledge transfer activities and appoint external services such as abattoir assessors, data processors and analysts. Steering group committees composed of managers, industry experts and other stakeholders oversee the health schemes and evaluate progress. In BPHS, six pharmaceutical companies are involved with sponsorship of the scheme and are represented in the steering committee.

3.3 Information flow from the assessments to the producers

The scheme managers coordinate the veterinary assessment dates that are communicated to both producers and assessors at least three months in advance. The producers can then plan their pigs' submission to the abattoirs on the appropriate assessments dates. Batches of pigs, i.e. a group of pigs from a single farm submitted to the abattoir on a particular date, are identified by their slapmarks. This is a unique official reference identifier for each holding consisting of an alphanumeric code tattooed on each shoulder. The health scheme assessments take place before the official inspections of offal and carcasses. Disease information is electronically recorded directly onto hand-held touch screen computers at the time of the assessment on the slaughter line. After each assessment day the assessors submit the electronically recorded information via email to a central database. These data go through a validation process to ensure freedom from errors (e.g. out of range scores, wrong dates, etc.). Figure 1 represents the information flow within the health schemes. A report summarising the findings for each batch of pigs submitted (including lesion prevalence data) is sent either by email or by post to each producer and their veterinarian within 48 hours of the assessment (see Figure 2 with the example for BPHS).

Benchmarking reports for each unit, presenting the results in a graphical format and providing comparisons with average figures of all the members of the health schemes, are sent to producers and veterinarians on a quarterly basis (see Figure 3 with the example for WPS). The information is held centrally and is used in routine descriptive epidemiological analyses to explore geographical and temporal distribution, the results of which are summarised in technical reports. These reports are made available internally and distributed to the health schemes' managers, assessors and sponsors. The data is also made available to research groups.

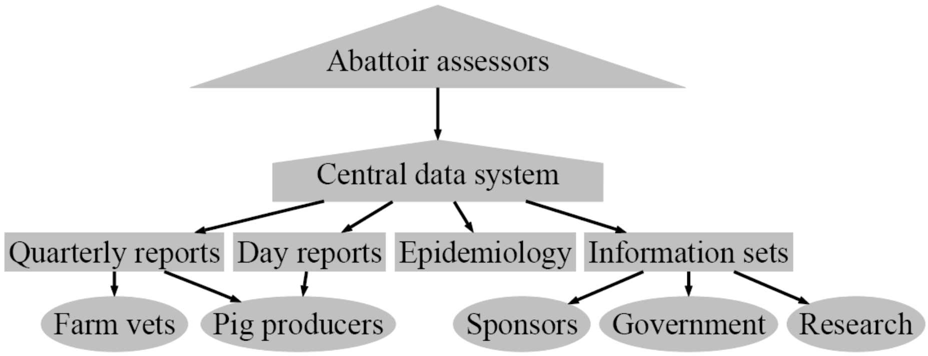
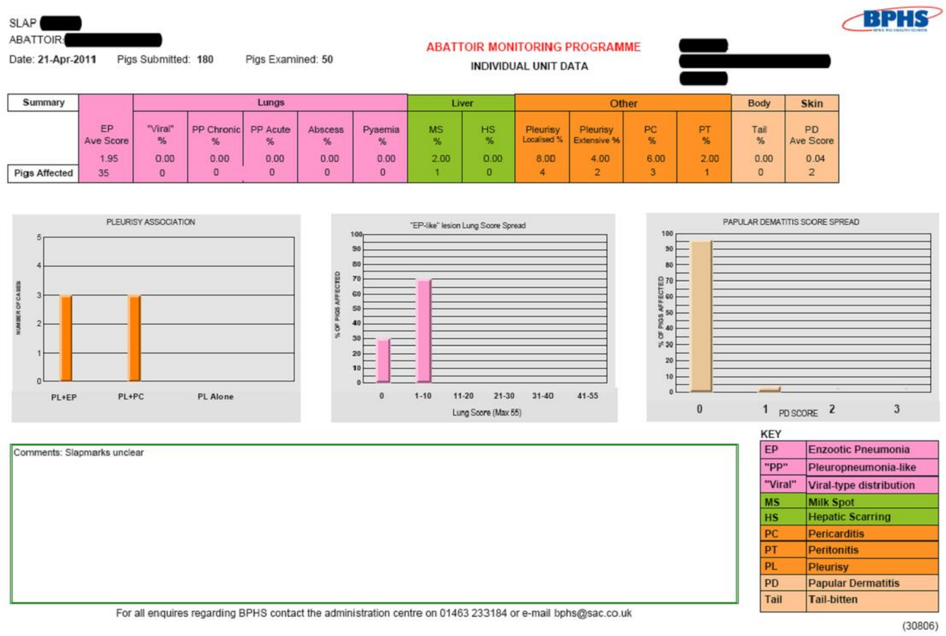


Figure 1. Diagram representing the flow of information in the health schemes, starting with the collection of electronic records of the gross pathology results in the abattoirs to the summary reports sent to the producers and veterinary advisors.



SLAP [redacted]
ABATTOIR: [redacted]
Date: 21-Apr-2011 Pigs Submitted: 180 Pigs Examined: 50

ABATTOIR MONITORING PROGRAMME
INDIVIDUAL UNIT DATA

[redacted]

BPHS

Summary		Lungs					Liver		Other				Body	Skin
	EP Ave Score	"Viral" %	PP Chronic %	PP Acute %	Abscess %	Pyaemia %	MS %	HS %	Pleurisy Localised %	Pleurisy Extensive %	PC %	PT %	Tail %	PD Ave Score
	1.95	0.00	0.00	0.00	0.00	0.00	2.00	0.00	8.00	4.00	6.00	2.00	0.00	0.04
Pigs Affected	35	0	0	0	0	0	1	0	4	2	3	1	0	2

Comments: Slapmarks unclear

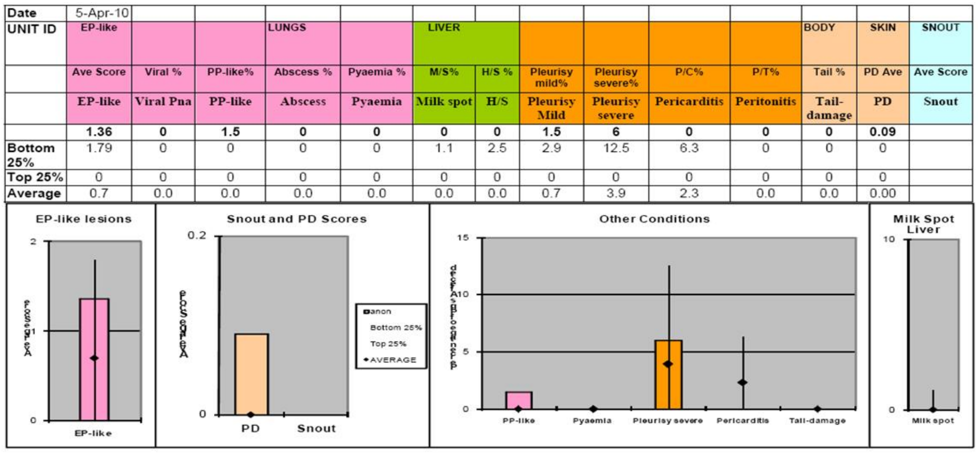
KEY

EP	Enzootic Pneumonia
"PP"	Pleuropneumonia-like
"Viral"	Viral-type distribution
MS	Milk Spot
HS	Hepatic Scarring
PC	Pericarditis
PT	Peritonitis
PL	Pleurisy
PD	Papular Dermatitis
Tail	Tail-bitten

For all enquires regarding BPHS contact the administration centre on 01463 233184 or e-mail bphs@sac.co.uk

(30806)

Figure 2. BPHS producer batch report containing the information on the prevalence of lesions in the batch assessed in the abattoir.



Date	5-Apr-10														
UNIT ID	EP-like			LUNGS		LIVER						BODY	SKIN	SNOUT
	Ave Score	Viral %	PP-like%	Abscess %	Pyaemia %	M/S%	H/S %	Pleurisy mild%	Pleurisy severe%	P/C%	P/T%	Tail %	PD Ave	Ave Score
	EP-like	Viral Pna	PP-like	Abscess	Pyaemia	Milk spot	H/S	Pleurisy Mild	Pleurisy severe	Pericarditis	Peritonitis	Tail-damage	PD	Snout
	1.36	0	1.5	0	0	0	0	1.5	6	0	0	0	0.09	
Bottom 25%	1.79	0	0	0	0	1.1	2.5	2.9	12.5	6.3	0	0	0	
Top 25%	0	0	0	0	0	0	0	0	0	0	0	0	0	
Average	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	3.9	2.3	0.0	0.0	0.00	

Figure 3. WPS quarterly producer report containing the information on the prevalence of the batch assessed in the abattoir and the benchmark figures on the averages found for the scheme.

3.4 Assessors and sampling strategies

The scoring is carried out by swine specialists trained in this method of testing on the abattoir post-mortem inspection line. WPS appoint the assessors directly. Originally, one veterinarian undertook the assessments and a non-veterinarian pig specialist was used as a back-up assessor. From 2010, two veterinarians carry out the inspections assisted by the non-veterinarian pig specialist. In BPHS, the assessors are appointed by an external contractor who is responsible for their recruitment and management. This scheme only recruited swine veterinarians as assessors. Fifty five veterinary assessors in total have participated at some point in the scheme. Both schemes aim to record lesions from a representative sample from each batch of pigs by assessing every other pig on the slaughter line (due to fast line speeds), until the end of the batch in the case of WPS and up to a maximum of fifty pigs in the case BPHS. All the large pig abattoirs in Britain where the plant operator gave the consent for the health schemes' inspections were recruited. WPS operates in three abattoirs in Scotland and BPHS in 14 abattoirs in England.

Both schemes carry out exercises to standardise the definition of the lesion across the inspectors. One veterinarian has been responsible for the training of all the other inspectors involved in the WPS assessments. The same veterinarian also participated in the training of BPHS assessors at the starting of the scheme. For WPS, once a year, all the inspectors undergo a refresher day where the same pigs are assessed by all the assessors in the abattoir line. For BPHS, three regional coordinators annually attend a standardisation day arranged by a veterinary advisor who is nominated by BPHS. Thereafter, the regional coordinators arrange and undertake regional standardisation days with all the other assessors. The regional coordinators will work on the line with two to three assessors scoring carcases simultaneously. This simultaneous scoring carried out in the abattoir line by WPS and BPHS aims to maintain the consistency in the scoring criteria across assessors by identifying and correcting potential misclassifications. Furthermore, BPHS aims to include at least two assessors per abattoir and each assessor should work in at least two different abattoirs, thereby minimising the clustering (at specific abattoir/herds) of potential operator bias.

3.5 Unique characteristics of WPS and BPHS

WPS was the first scheme implemented in Great Britain, and covers virtually all of the commercial finisher units located in Scotland. WPS carries out assessments on five days per quarter and aims to assess every producer every quarter. BPHS was developed after WPS following the same principles but implemented on a much larger scale. BPHS assesses and records the results from the inspections for all the batches of pigs slaughtered on the assessment days regardless of the membership status of the producers (i.e. results for non-members are also recorded). All the assessments combined (members and non-members) would cover, with at least one assessment per year, 75% of commercial finishing pigs farms in England and Wales (assuming a total of c.1,400 commercial pig units (BPEX, 2011)). Between one and four assessment days per month are carried out at each abattoir. BPHS aims to make at least one assessment per quarter for each member slapmark as does WPS. Other characteristics of the health schemes are presented in Table 3 with comparison between WPS and BPHS. These descriptions use data for 2010 to provide indicative figures for the schemes.

Table 3. Comparing WPS with BPHS characteristics over 2010.

Lesion	Wholesome Pigs Scotland	BPEX Pig Health Scheme
Starting date	March 2003	July 2005
Number of herds assessed	157	516 members 520 non-members
Number of inspections per year	20,719 pigs 405 batches	180,539 pigs 4,185 batches
Median and IQR‡ for number of pigs assessed per batch	Median 47 IQR‡ 24-75	Median 50 IQR‡ 40-50
Median and IQR‡ for number of assessment per producer year	Median 2 IQR‡ 1-4	Median 3 IQR‡ 2-5
Number of abattoir days[Ŧ]	40	356
Number of abattoirs	3	14
Number of assessors	3	37
Representativeness	Approx. 100% of the commercial units. Membership is a requirement of QMS Farm Assurance Scheme.	Approx. 75% of the commercial units.
Funded by	Membership £50 per year. Levy funds.	Membership £50 per year. Levy funds, Defra (2005-2008) and pharmaceutical companies.
Main services	Benchmarked results on the batch prevalence detected in the abattoirs to the producers and their vets. Individual reports are commented on by the veterinary assessor.	Benchmarked results on the batch prevalence detected in the abattoirs to the producers and their vets. Occasionally, individual reports are commented on by the veterinary assessor.
Additional services	Collection of blood samples for serological testing. Collection of bile fluid samples for detection of mycotoxin exposure. Ear swabs for sarcoptic mange inspection.	The possibility of collecting additional samples is offered by the scheme but it has never been used.
Additional use of the data	Exploring temporal trends and geographical distribution.	Exploring temporal trends and geographical distribution. Consistency across abattoirs
Internal validation	Scores by different assessors for the same pigs are compared.	Regional standardizer covers different regions to maintain the consistency of the assessments.
Programme cost per year	Approx. £43,000.	Approx. £450,000.

IQR‡: Interquartile range.

Ŧ Abattoir-days: Sum of total number of inspection days for all abattoirs in 2010.

4 Discussion

Health schemes have become one of the most important tools available to British farmers and their veterinarians for monitoring and tackling important health problems affecting efficiency of production and/or animal welfare.

4.1 Compliance of health schemes as a monitoring tool

Conventionally, the use of abattoir records as a diagnostic tool has been limited by the lack of accuracy in the identification of the lesions. Enoe et al (2003) compared routine abattoir inspection (traditional) whose principal objective is to warrant food safety, with a more detailed inspection that focused on a number of pigs and specific organs. Both systems had adequate specificity and the sensitivity of detection of the conditions improved considerably when detailed inspection was carried out. These results could be extrapolated to the health schemes, in which detailed inspections are carried out and adequate sensitivity and specificity would be expected.

The median number of pigs assessed per batch was close to 50 in the case of WPS, and is the target number established by BPHS. This number is adequate to detect conditions presenting with at least 5% prevalence, assuming an average batch size of 200 pigs (Cannon and Roe, 1982). Whilst the prevalence estimated by the health schemes for conditions with high or low true prevalence is adequate, the level of confidence and/or precision would be diminished for those conditions whose true prevalence approaches 50% (Cannon and Roe, 1982). In many scenarios, the purpose of the abattoir monitoring would be assessing the impact of an intervention for which the ability of the schemes to detect the changes in prevalence would be more useful than just simply measuring the disease level at a point of time.

Both schemes fail to achieve at least one assessment per herd slapmark in every quarter. The more assessments per slapmark, the more accurate the estimate of within-herd prevalence for the different conditions. This is particularly important for conditions such as milk spots and respiratory diseases that show seasonal patterns and for which occurrence appears to be clustered at batch level (Stark, 2000; Sanchez-Vazquez et al, 2010a; Sanchez-Vazquez et al, 2010b). In those scenarios, the results obtained from one assessment might not be representative of the over time prevalence for the herd since the lesion prevalence may vary between the different batches. The health schemes attempt to encourage the submission of multiple batches for assessment but in many cases the producers fail to send the pigs on the specific dates when the assessments take place (e.g. through simply missing dates, not having pigs ready for submission on the fixed dates or sending pigs to other non-participating abattoirs).

4.2 Individual farm feed-back

The main objective of the pig health schemes is to feed back the results on prevalence of selected conditions to the individual producers and their veterinarians. Apart from the day report with the individual herd prevalences, the producers receive a summary of the results every quarter benchmarked against the average for all the producers in the scheme. These reports not only increase the awareness of producers and their veterinarians individual herd problems but also allow the comparison of herds within their own businesses and the comparison of their own herds with the industry as a whole. The benchmarked results seek to stimulate peer/industry pressure which would help to motivate an intention to control disease, as was suggested by the socio-ecological model on farmers' attitude to control diseases proposed by Ellis-Iversen et al (2010). The producers and their veterinarians use the feed-back from the health schemes to assess vaccine and worming interventions. In an internal survey of 55 producers and 42 veterinarians (carried out by BPEX in 2007), 60% and 80% of them, respectively, reported taking actions on farms to address health issues as a result of the information contained in the BPHS reports (unpublished data). It is also likely that veterinarians whose practices have as clients both BPHS members and non-members, use the results from members to review and implement health strategies across all clients, and in this way, non-members benefit indirectly.

4.3 Further uses of the health schemes data

The collective use of the individual reports from the health schemes creates an opportunity to add value to these abattoir data. In a previous report, BPHS was considered to provide standardised results and reliable trends (Stark and Nevel, 2009). The health schemes make use of epidemiological tools to explore time-trend and geographical distributions of the lesions. The data from the health schemes has also been of use for epidemiological studies to investigate the risk factors affecting some of these conditions (Sanchez-Vazquez et al, 2010a; Sanchez-Vazquez et al, 2010b) and their potential association with Salmonella infection (Smith et al, 2011).

The combined results from both schemes provide a powerful tool for prevalence estimations on endemic diseases in the British pig finishing herd. The accuracy of the observed prevalence will depend on the representativeness of the batches assessed and of their herds. WPS monitors almost all the commercial farms in Scotland, since being a scheme member is a mandatory requirement of membership of the Quality Meat Scotland farm assurance scheme in that country. BPHS is estimated to assess 75% of the English and Welsh commercial herds either as members or non-members. In England and Wales, BPHS membership is not obligatory for farm assurance schemes. In short, it could be considered that commercial producers are well represented by the health schemes' assessments and these provide a useful guide as to the prevalence of some important endemic diseases in finishing pigs.

4.4 Limitations of the schemes

The gross lesions assessed in the schemes persist for a limited time span depending on the speed of resolution of the particular pathology. For example, other work has shown that chronic pleurisy could only be detected for up to three months (Sorensen et al, 2006) and milk spots only persisted for a month following infection (Stewart and Hoyt, 2006). Lesions associated with early challenges in the life of the pigs will therefore not be detectable in the abattoir and cannot be monitored by the schemes. Furthermore, those pigs that suffer a pathological condition on the farm and do not make it to the abattoir (i.e. if they die) will not be represented in the batch assessments contributing to an underreporting in the prevalence of the condition. It is important that the results of the health inspections in the abattoir are carefully interpreted within the context of the current and historical information available on the specific batch of pigs and the farm in general.

The value of the health scheme reports may be more limited for all-in-all-out systems as by the time the results are available they are of little use for that particular group of pigs and the next group may come from a different source. In addition, the frequency of the assessments is not ideal for the rapid detection of exotic disease threats or emerging diseases in individual herds such as highlighting contagious diseases (e.g. classical or African swine fever, highly pathogenic strains of swine influenza or porcine reproductive and respiratory syndrome virus). Hence, farm monitoring and syndromic surveillance are not replaced but are complemented by the health schemes.

None of the lesions investigated is pathognomonic for a particular disease and only a few (e.g. enzootic pneumonia-like lesions, milk spots and papular dermatitis) can be considered good proxies for specific pathogens (Cargill et al, 1997; Sorensen et al, 2006; Stalker and Hayes, 2007; Meyns et al, 2011). For the producers and their veterinarians, however, knowing the occurrence of the lesions is of value even if they have a complex aetiology e.g. pleurisy, abscess (Huey, 1996; Enoe et al, 2002), as they are production-limiting conditions not easily detected when the animal is alive. Thus, they can monitor their occurrence to keep it at what they consider to be an "acceptable" prevalence level and/or implement husbandry practices and health strategies to reduce the occurrence of these conditions.

4.5 Conclusions and future actions

Health schemes are well-organised initiatives, with a complex logistical structure which allows coordination of inspections across different abattoirs and they contribute considerably to producer and veterinarian awareness of endemic diseases. Additionally, the health schemes contribute to the understanding of the national situation and progression of the endemic diseases. The future of the health schemes depend upon the availability of funding and the success in the expansion of BPHS across all the commercial finishing units.

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Chapter III

The Identification of Risk Factors for the Presence of Enzootic Pneumonia-Like Lesions and Pleurisy in Slaughtered Finishing Pigs Utilizing Existing British Pig Industry data

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Abstract

Abattoir monitoring in slaughtered finishing pigs is carried out as part of established health schemes. Enzootic pneumonia-like (EP-like) lesions and pleurisy are the two more prevalent conditions reported, being associated with reduction in performance traits. This study combined records on EP-like lesion and pleurisy from 129,819 slaughtered pigs with information from the farms of origin in order to identify those production characteristics that may influence the prevalence of these lesions. Five hundred and five farms were recruited using the information available in national quality assurance programmes (QAPs): pig stocking levels; feeding practices; housing systems and geographical location. Relevant epidemiological information common to these databases was extracted. Generalized linear mixed models were used for multivariable analysis, allowing for clustering at batch level. Geographical location of the finishing unit appeared to be a statistically significant risk factor for EP-like lesions and pleurisy. Part-slatted floors also appeared as a potential risk factor for the presence of these two conditions, versus the use of solid floor with bedding which appeared protective. This study demonstrated the potential of combining abattoir and QAPs' data to perform epidemiological analysis which may lead the British pig industry to a better understanding of how the farm characteristics and geographic location could influence the prevalence of EP-like lesions and pleurisy.

1 Introduction

Coordinated industry-wide pig abattoir lesion scoring has been implemented in Great Britain with the development of health schemes; in 2003 when Wholesome Pigs Scotland (WPS) started and in 2005 with the British Pig Health Scheme (BPHS). These schemes report the presence of twelve different conditions detected in the slaughtered pig (in the pluck and on the skin), many of which have been associated with a reduction in performance traits and consequent increases in production costs. The cornerstone of the health scheme's success has been the frequent feedback of benchmarked results from routine abattoir inspections to the participating producers and their herd veterinarians helping to increase their awareness of the occurrence of these subclinical diseases in their herds.

In addition to the more recent implementation of these health schemes the pig industry, supported by the government and food industry, had previously developed quality assurance programmes (QAPs). These initiatives were created in response to an increasing demand from the consumer for warranted animal health and welfare standards. Through regular periodic audits they certify the compliance of their members with the minimum agreed standards of pig production for the scheme (e.g. pig housing and management practices; sources of pigs, feeding, hygiene, medications, etc.). The QAPs also collect and document a large amount of information on farm production descriptors (e.g. type of housing, type of feeding, number of finishing pigs, number of sows, etc.).

The two types of lesion that have remained most prevalent since the introduction of the health schemes have been enzootic pneumonia-like (EP-like) lesions and pleurisy. In 2007 the overall prevalence of slaughtered pigs reported with these conditions was 28% and 11% respectively for the WPS and BPHS aggregate annual records. EP-like lesions are reported when the gross pathology observed is consistent with the expected lung lesion caused by *Mycoplasma hyopneumoniae* (the recognised causative agent of EP); i.e. a confluent consolidation affecting the cranioventral regions of the lungs; with appearance ranging from dark red to greyish pink (Jubb et al., 1993).

Although lesions are not pathognomonic for *M. hyopneumoniae* infection and other organisms have been associated with identical lesions, e.g. *Mycoplasma hyorhinis* and chronic bacterial infection. Pleurisy (or pleuritis), which denotes inflammation of the pleura, is reported in the health schemes under two pathologies: extensive pleurisy and/or as a pleuropneumonia-like lesion. Extensive pleurisy is commonly manifesting as chronic fibrous, or less commonly more acute fibrinous, pleural adhesions. The lesions are not pathognomonic for any particular pathogen and various infectious agents are reported to be involved in the development of pleuritic lesions including *Actinobacilus pleuropneumoniae*, *Pasteurella spp*, *Mycoplasma. hyorhinis*, swine influenza and *Haemophilus parasuis* (Enoe et al. 2002; Straw et al., 2006). Discrete pleuropneumonia-like lesions (most frequently involving *A. pleuropneumoniae* or *Pasteurella multocida* infection) are reported separately from lesions involving only adhesions of the visceral and/or parietal pleura. The high prevalence of these EP-like lesions and pleurisy at slaughter is a constant reminder of the continued importance of respiratory disorders in pig production and the significant financial losses to the industry incurred by such disorders (Straw et al., 2006).

It is has been reported that environmental factors and management practices play an important role in the development of respiratory conditions, together with the presence of the infectious agents (Done, 1991; Jubb et al., 1993; Stärk, 2000). However carrying out large scale epidemiological studies for these conditions necessitates significant budgetary and logistic resources as these lesions cannot easily be detected in the live pig. Previous studies have used abattoir reports to perform epidemiology-based analysis to investigate on-farm risk factors for the presence of respiratory conditions in the slaughtered pigs (Hurnik et al., 1994; Stärk et al., 1998; Clevelance-Nielsen et al., 2002; Enoe et al. 2002; Ostanello et al., 2007), but this approach has not been exploited in the UK.

The study described here aimed to optimise the use of the existing pig abattoir scoring reports by linking them to the farm information collected through the QAP in order to investigate which management practices and farm characteristics may be predictors for the prevalence of EP-like lesions and pleurisy.

2 Material and Methods

2.1 Data source

Farm information was obtained from the three main farm QAPs: Quality Meat Scotland (QMS) for Scotland and Assured British Pigs (ABP) and Genesis Quality Assurance (QA) for England and Wales. Current and historic data available at the time this study started were used, covering the two year period between October 2005 and September 2007. This information was merged with the herd abattoir records from the health schemes WPS and BPHS. The study population for this project consisted of those pig producers that were members of a health scheme and were also part of any of those three QAPs.

Farm was defined as a site that had a specific QA number and a Defra herdmark (Defra, PRIMO rules). This latter is an individual official reference for each holding, consisting of an alphanumeric code, which is also used to identify those pigs sent to the abattoir by its application on each shoulder as a tattoo, otherwise known as a slapmark. A batch was defined as a group of pigs from a single farm submitted to the abattoir on a particular date. The slapmark is used to identify and report the abattoir scoring results for each batch of pigs assessed under the health schemes.

2.1.1 Data management and data mining.

2.1.1.1 Farm data

Revision of historical information available revealed three main data problems: i) existence of missing values; ii) discrepancies in the date on which the different farm characteristic descriptors were updated; and iii) changes over time in some of the farm characteristics, especially for stocking numbers which commonly presented fluctuations over time.

Farm variables that were common to the three different quality assurance schemes, and could potentially be a "proxy" for a risk/protective factor for the occurrence of EP-like lesions or pleurisy in finishing pigs, were identified. The following variables met these criteria: total number of finishing pigs and sows; flooring characteristics in the finishing pigs housing; use of wet-feeding; the presence of a breeding unit on the site; and reported use of outdoors accommodation at any stage of production.

A database combining QA information was created with the assured member farm characteristics for a specific herdmark. The information concerning the stocking numbers present in the farms at the time of the inspections and the date at when the information was updated were include in the database. For other variables (e.g. flooring characteristics, feeding system) which were farm structural characteristics and management practices unlikely to change within the two year study period, atemporal farm characteristics were established. This approach allowed our database, and posterior analyses, to account for the potential presence throughout the whole study period of these characteristics reported to be present in some but not all the audits. A summary of all the different variables considered in the analysis can be found in Tables 1 and 2.

Table 1. Categorical variables.

Variable	Classes	Count data		Binary data	Description
		Units	N (percentage)	N farms yes (percentage)	
QA Programme	QMS ABP Genesis QA	Farms Farms Farms	166 (33) 149 (29) 190 (38)		QA programme from which the farm characteristics have been obtained
Health Scheme	WPS BPHS	Batches Batches	542 (20) 2108 (80)		Health Scheme where the abattoir scoring data have been reported
Location	North [(a)] Scotland South East [(b)] South West [(c)]	Farms Farms Farms Farms	113 (22) 166 (33) 179 (36) 47 (9)		Geographic area where the farm was located
Breeding	Yes/no			212 (42)	Having a breeding herd
Production all indoors	Yes/no			459 (91)	No records for stages of outdoors production
Use of wet-feeding	Yes/no			72 (14)	Reported use of wet-feeding
Use of solid floor with bedding	Yes/no			393 (78)	Reported use of solid floor with bedding
Use of part slatted floor	Yes/no			98 (19)	Reported use of partly slatted floor
Use of full slatted floor	Yes/no			128 (25)	Reported use of fully slatted floor

[(a)] North England; York and the Humber.
[(b)] East Midlands; East Anglia and South East.
[(c)] West Midland, Wales and South West.

Table 2. Continuous variables.

Variable	Units/ Classes	Mean	Median	25th Percentile	75th Percentile	SD	Description
Number of finishers	Count	3536	2500	1350	4296	3599	Number of pigs at the time of farm inspection
Number of sows	Count	223	0	0	366	328	Number of sows at the time of farm inspection
Pig farm density in the area	Farms / km^2	0.033	0.021	0.01	0.044	0.03	Calculated farm density on number of farms per km^2

To investigate area differences in lesion prevalence, Great Britain was divided into four different areas (see Figure 1): a) Scotland; b) North England; Yorkshire and the Humber (North); c) East Midlands, East Anglia and South East (South East); and d) West Midlands, Wales and South England (South West). Information from the pig industry concerning location of the abattoirs participating in the scheme and of the farms supplying pigs to those abattoirs was used in deciding this geographical divisions; as representation of a proxy for abattoir farm capture areas. Density of farms per area for each holding, expressed in number of pig farms per km2, was calculated using the map reference for the postcode of 1,100 farms. ESRI ArcGIS 9.2 was used to perform these calculations.

Figure 1. Map presenting the geographical divisions used to study farm location effect.

2.1.1.2 Abattoir data

EP-like lesion scores, representing the approximate percentage of lung area showing consolidation, were recorded on a scale from 0 to 55 in 2.5 steps. Pleuritic lesions were scored in two ways: a) pleural adhesions were recorded using three categories 0, 1 and 2; 1 indicating adhesions between lung lobes only, 2 indicating adhesions involving the visceral pleura and/or the parietal pleura and 0 indicating an absence of adhesions and b) pleuropneumonia-like lesions which are reported as a binary, present (1) or absent (0). For this study we considered presence of pleurisy when any of these two lesions were present (i.e. pleural adhesions or pleuropneumonic-like lesions). The scoring was carried out by swine veterinarians trained in this method of recording, assessing at the abattoir inspection line. Both schemes aimed to obtain a representative sample of the batch of pigs assessing every other pig on the slaughter line. However they differed in one specification of the sampling criteria strategy; WPS sampled pigs up to a maximum of 150 per batch whereas BPHS sampled up to 50 pigs.

2.1.1.3 Merging of farm and abattoir data

The abattoir scoring results reported for a specific slapmark were attributed to the compiled QA farm characteristics with a matching herdmark. A restriction criterion was used to join the abattoir information recorded for the twelve months after the date the farm stock numbers were updated.

No historical information was kept in the record for QMS farms, for those records the farm information was related to the lesions reported in the abattoir within one year before and one year after farm inspection. This was done with the aim of providing satisfactory number of batches of pigs assessed per farm to be included in the analysis.

The process described above lead to a dataset of QA information from 505 farms, including 786 audits where the stocking information was updated. This dataset included the records from 2650 batches of pigs from those farms assessed through the health schemes. These assessments integrated a total of 129,819 pigs inspected; with a mean of 49 pigs per batch (median 50) and standard deviation of 28 (Q1 40 and Q3 50).

2.2 Statistical analysis

This investigation aimed to study the risk/protective factors associated with the prevalence of EP-like lesions and pleurisy. We investigated the presence of the lesion as a binary response at the pig level; considering the absence as a baseline.

Initially the analysis comprised univariate explorations to investigate the associations between the observed prevalence for EP-like lesions and pleurisy and the different farm factors considered. Next the variables were included in a multivariable generalized linear model and were retained in the model if the individual Wald test was considered statistically significant ($p<0.05$) (Dohoo et al., 2003). Pig farm area density and number of finishing pigs were studied in our model both as continuous and as categorical variables. The number of sows was studied as categorical variable with baseline class being no sows present on the farm. The troughs and the inflection points in the density function were used to establish data-derived cut off points to the create categories for each of these continuous variables (see Table 3). Temporal variations were also investigated in the model in three time periods: monthly, quarterly and six monthly. A logarithm transformation for the number of finishing pigs and pig farm area density was used to ensure robust outputs for this continuous variable in the regression analysis. The variables retained in our initial multivariable model were included in a mixed effects binomial logistic regression multivariable model. Random effects at the farm and batch level were investigated. The goodness of fit of the models was evaluated by examining the Akaike's information criterion (AIC) results. Additionally, computed analysis of deviance was used in the comparisons for nested models. In the final model, variables were considered to remain significant on the basis of the Wald test ($p<0.05$). All the above mentioned analyses were performed with R version 2.7.1 (libraries stasts and lme4) from R Development Core Team (2008). R: A language and environment for statistical

computing. R foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07, URL http://www.R-project.org.

Table 3. Continuous variables studied by classes.

Variable	Classes divisions	Number of farms (percentage)	Number of audits [1] (percentage)
Number of finishers present in the farms	More than 9000 finishers	23 (5)	28 (4)
	Between 9000 and 2500 finishers	182 (36)	300 (38)
	Less than 2500 finishers	300 (59)	458 (58)
Number of sows present in the farms	More than 600 sows	28 (6)	53 (7)
	Between 150 and 600 sows	145 (28)	257 (32)
	Between 15 and 150 sows	31 (6)	46 (6)
	None sows present	301 (60)	430 (55)
Pig farm density in the area	More than 0.09 farm per Km^2	51 (10)	- [d]
	Between 0.09 and 0.03 farms per Km^2	192 (38)	- [d]
	Less than 0.03 farms per Km^2	262 (52)	- [d]

[1] Information on the number of animals is updated.
[d] Farm density does not vary between the audits.

3 Results

The results from the multivariable mixed models for EP-like lesions and pleurisy that provided the best goodness of fit to the data are presented in Tables 4 and 5 respectively. These were mixed models that incorporate clustering at batch level instead of farm level. The three time length periods studied were not significantly associated with the models.

Table 4. Estimated Odds Ratios in the multivariable mixed model including variables associated with presence of EP-like lesions in finishing pigs and allowing for random effects at batch level. N=505 farms.

Farm variable	Level	Odds ratio	95% Confidence intervals
Intercept		0.08	0.04 - 0.12
Part slatted floor		1.44	1.21 - 1.72
Solid floor with bedding		0.79	0.66 - 0.94
Log number of finishers		1.17	1.07 - 1.27
Area [1]	North England [a]	3.27	2.63 – 4.07
	South East [b]	2.25	1.81 – 2.81
	South West [c]	4.23	3.23 – 5.53
Farm density category [2]	Median	0.39	0.28 - 0.52
	Low	0.31	0.23 - 0.41

[1] Baseline is Scotland.
[a] North England; York and the Humber.
[b] East Midlands; East Anglia and South East.
[c] West Midland, Wales and South West England.
[2] Baseline is high farm density area.

Table 5. Estimated Odds Ratios form in the multivariable mixed model including variables associated with presence of pleurisy in finishing pigs and allowing for random effects at batch level. N=505 farms.

Farm variable	Level	Odds ratio	95% Confidence intervals
Intercept		0.15	0.11 - 0.22
Part slatted floor		1.27	1.08 - 1.44
Solid floor with bedding		0.71	0.64 - 0.82
Wet feeding		1.48	1.28 - 1.71
Breeding herd on the unit		1.33	1.17 - 1.51
All production Indoors		0.72	0.59 - 0.87
Health Scheme (1)	BPHS	1.51	1.3 - 1.76
Farm density category (2)	Median	0.4	0.31 - 0.50
	low	0.42	0.33 - 0.53

(1) Baseline is WPS.

(2) Baseline is high farm density area.

3.1 Results for EP-like lesions

Geographical location has clearly the highest estimated odds ratios of all the variables studied: the odds of a slaughtered pig from South West of England and Wales being reported as having EP-like lesion is 4.22 times higher, 95% confidence intervals (CI) 3.23-4.84, than the odds of a pig from Scotland. The other two regions investigated also presented higher risk compared with the observed prevalence in Scotland (South East OR 2.25, 95% CI 1.81-2.52; North OR 3.27, 95% CI 2.63-3.65). A weak positive association with presence of EP-like lesions (OR 1.44, 95% CI 1.21-1.57) was estimated for farms with part slatted flooring compared with those not using this type of floor. In contrast those farms using solid floors with bedding seemed to have a lower risk of EP-like lesions (OR 0.79, 95% CI 0.66-0.86) compared to those not having solid floors. Increasing number of finishing pigs in the farm also increases the odds of EP-like lesions. Those farms from areas of low and median pig farm density (i.e. less or equal than 0.09 pig farms per Km^2) had a lower risk of EP-like lesions (OR 0.39, 95% CI 0.28-0.45 and OR 0.31, 95% CI 0.23-0.36 respectively) than those from areas of higher density (i.e. more than 0.09 pig farms per Km^2).

3.2 Results for pleurisy

A mild but significant association (OR 1.27, 95% CI 1.08-1.32) with pleurisy was observed for those farms using part slatted floor versus those not using this type of floor. Conversely those farms using solid floor with bedding appear to have a lower risk of pleurisy (OR 0.71, 95% CI

0.64-0.79) than those not using it. Those farms feeding wet-feeding to the finishing pigs had a higher risk of pleurisy (OR 1.48, 95% CI 1.28- 1.59) than those using dry feed. Farms that had a breeding herd had a higher risk of pleurisy (OR 1.33, 95% CI 1.17-1.41) than those farms registered just as finishing units. A smaller risk of pleurisy was detected in those farms where all the production was indoors (OR 0.72, 95% CI 0.59-0.79) compared with those farms which reported production stages outdoors. The producers belonging to BPHS (English and Welsh farms) had a higher risk of pleurisy (OR 1.51, 95% CI 1.3-1.63) that those belonging to WPS (Scotland). Those farms from areas of low and median pig farm density had a lower risk of pleurisy (OR 0.42, 95% CI 0.33-0.47 and OR 0.4, 95% CI 0.31-0.45 respectively) than those from areas of higher density.

4 Discussion

This was a retrospective study to identify risk/protective factors for two main respiratory conditions reported at the abattoir slaughter inspections (EP-like lesions and pleurisy) which used the existing information available in the databases of farm QA companies and Health Schemes. This was the first time in Great Britain the information collected by those initiatives has been combined for epidemiological analyses adding an extra value to this information initially collected for other purposes. This analysis aimed to provide the British pig industry with a better understanding on the risk factors associated with EP-like lesions and pleurisy.

4.1 Area and density

The location of the farm appears to be an important predictor for the prevalence of EP-like lesions and pleurisy. Slaughtered pigs from South West region (West Midlands, Wales and South West of England) had the highest prevalence of EP-like lesions. The slapmarks assessed through BPHS (i.e. English and Welsh producers) had a higher risk of pleurisy than those reported through WPS (i.e. Scotland). The difference in EP-like lesions and pleurisy prevalence of such large geographical zones may be due to genuine regional differences in health status (i.e. the presence of specific pathogens) and /or differences in husbandry, in particular the type of accommodation used. Controlled ventilation systems may be more likely to be used in Scotland compared to South of England and Wales. There may also be an effect of the presence of some large production enterprises and their respective general health statuses on the overall health status of the region.

Herds located in areas of low and medium pig farm density appeared to have lower risk of reported EP-like lesions and pleurisy. Our finding is in line with previous studies where pig geographical density is reported to be a risk factor for pleurisy (Cleveland-Nielsen et al., 2002; Maes et al. 2001). Farms in areas with high pig density could face increased risk of local spread (e.g. air borne; higher likelihood of pig and pig by-product movements, etc.) of some infectious diseases (e.g. *M. hyopneumoniae* and porcine reproductive and respiratory syndrome virus). It was not possible to calculate the true pig farm density due to the presence of farms for which the postcode was not available, and the fact that the study did not include those pig farms that were not registered with any of the three participating QA schemes. It may be assumed, however, that the calculated farm density used in this study is a reliable proxy for the true pig farm area density distribution.

4.2 Farm characteristics

Similar results for EP-like lesions and pleurisy were obtained from the investigation of flooring types. Partly slatted floors appear to be a risk factor for higher prevalence of these two conditions, whereas the use of solid floors with bedding seemed to be protective. This has been previously reported (Stärk; 2000) with the explanation that the use of bedding material could be beneficial to insulate the pig from the floor temperatures. However, in this case, it is perhaps more likely that this association is a reflection of the nature of the building characteristics. Partly slatted flooring is more common in 20-30 year old buildings with low ceilings and poorer ventilation which may result in less than optimal environment in which the pigs are growing, increasing the prevalence to respiratory conditions. Also a considerable number of farms using solid floors with bedding may be involved in multisite all-in-all-out productions systems with subsequent benefits on the pathogen transmission control.

Larger number of finishing pigs on site appears to increase the risk of EP-like lesions. Herd size as potential risk factors for respiratory swine diseases has been consistently reported in the literature (Stärk; 2000; Gardner, et al.; 2002). Gardner et al (2002) specifically discussed the role of herd size as a potential risk factor for pig diseases evaluating different explanations such the risk of introducing infectious agent from outside the herd (e.g. with carrier pigs; by airborne routes), and risk of maintaining and transmission of infectious agents within herds. The authors also discussed the presence of management factors that are associated with herd size (e.g. production systems; diseases control practices, labour structure and organization). Those factors correlated with the herd size that were no available in our study could have had a confounder effect on the association of the prevalence of EP-like lesions and number of finishing pigs which needs to be considered for in its interpretation.

Those herds that have reported all phases of production to be indoors had a lower risk of pleurisy compared with those that have some stage of the production outdoors. Extreme external temperature fluctuations could make outdoor pigs more susceptible to respiratory diseases; the potential effect of the meteorological factors on pig respiratory disease has been reviewed by Done (1991).

Those units using liquid feeding appeared at higher risk for the presence of pleurisy. This seems to contradict the current view that wet-feeding has an indirect benefit for overall pig health especially by favouring the process involved in digestion (Gill; 2007) and considering the potential collateral benefit of this feeding system for respiratory problems by reducing the presence of aerial dust. Our finding might not necessarily reflect the direct effect of wet- feeding but may be an indicator for other features of production (e.g. more intensive production; specific environmental control). Cleveland-Nielsen et al (2002) also found that dry-feeding had potential a protective effect against pleurisy.

4.3 Breeding animals present in the unit

The presence of breeding animals within the unit appears in this study to be a potential risk factor for pleurisy in finishing pigs. Similar findings have been reported for high health herds by other study based on abattoir lung scoring (Enoe et al. 2002), but contrasting conclusions have been reported by Stärk (2000) and Done (1991); with the latter study more focussed on pneumonic lesions. The latter authors argued that finishing farms are considered at higher risk of respiratory disease than breeding-finishing farms as they rely on other sources for weaner re-stocking. This would subsequently increase the chance of introducing infectious agents into the herd. The association observed here could reflect an increase in the health status in the weaner sources and possible better batch management to reduce mixing of the pigs from different sources compared with historical situations. The increasing preponderance, in the UK industry, of larger integrated multisite operations with perhaps stricter health controls could be reflected in this finding. This would mean that this "long-standing" potential risk factor could now have a lower impact on a finishing farm health status. However information on weaner source was not available in this study and therefore its true role could not be investigated.

4.4 Constraints and further discussion

An interesting output of the statistical analysis is that the models with better goodness of fit were obtained accounting for clustering at batch level rather that at farm level. This indicates the presence of greater variation in the prevalence of EP-like lesions and pleurisy between batches than between farms. This finding suggests that batch reports were not representative of the overall farm prevalence patterns for these two respiratory conditions; perhaps a consequence of variation in health status of the incoming stock on finishing units.

Most of the associations reported in these analyses (except for the ones for EP-like lesions related to location) although robust were weak associations (odds ratios close to one) indicating that only marginal differences may exist between exposed and unexposed groups. The sample size included in this study (505 farms) would have helped to detect these weak associations. It is worth noting that for the interpretation of the outputs from this study the observations were recruited from members of pig health schemes and caution needs to be applied when attempting to extrapolate these findings to other populations (e.g. non-members units or other countries) as these may be biased toward the study population of pig producers.

One potential drawback in this study was the use of information from existing databases. The datasets may have contained flaws for some of the QAPs records (e.g. the presence of unrecorded changes over time in some of the farm characteristics, inconsistent recording of the farm characteristics) which could have introduced information bias. However it was assumed that these errors were not differential bias, and that these would be equally present in either the exposed or the unexposed group (concerning the farm factors studied) regardless of the prevalence of these conditions. Moreover to minimise this problem, this study did not rely on the information collected on just one farm audit but also has reviewed and contrasted the historical information which was thus included in the combined database used for the analyses.

Seasonal variations have been reported for respiratory conditions (Done; 2001) however the temporal divisions investigated were not chosen as a significant predictor in the statistical model used.

An important limitation in this study was the lack of information on other variables that might play a role as confounders in predicting of the occurrence of the conditions investigated: e.g. the implementation of health interventions (either vaccines or treatments); the sources of the pigs; the presence of specific infectious agents; and pig handling and husbandry practices. The statistical approach used for the analyses (generalized linear mixed model) would have helped to control for the effect of some of these confounders and other factors occurring at batch level, at the same time allowing to cope with the statistical clustering present at this level for both outcome (EP-like lesions or pleurisy) and predictors (Dohoo; 2008).

4.5 Conclusion and future actions

This study has demonstrated the potential of using the existing data available through Health Schemes and QAPs in order to provide epidemiological analysis of value to the British pig industry. By exploring these data, this project has contributed to a better understanding of farm characteristics that may influence the prevalence of EP-like lesions and pleurisy within the British pig industry and their geographic distribution. These outputs may serve as a baseline for future studies on pig disease prevention and control in Great Britain.

Increasing the reliability and detail of the information concerning farm characteristics and production practices could form a basis for the implementation of risk-based surveillance policies that could help to optimize resources to the benefit of both the industry and governments funds (Stärk et al; 2006).

Further planned study involves the investigation of risk factors for other conditions recorded in the health schemes and, by utilising subsets of the data with more detailed descriptors of farm production practice, to investigate other possible risk factors.

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Chapter IV

The Identification of factors influencing the occurrence of milk spot livers in slaughtered pigs: a novel approach to understanding *Ascaris suum* epidemiology in British farmed pigs

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Abstract

Ascariosis is the most important internal parasitism present worldwide in farmed pigs. Milk spots are healing lesions occurring when *Ascaris suum* larvae migrate through the liver. This study aimed to identify current husbandry practices (e.g. wet/compound feeding, outdoors/indoors production, bedded/slatted floors) that influence the prevalence of milk spots in batches of slaughtered pigs, accounting for geographical locations and seasonality. Farm information was accessed through the British farm quality assurance programmes (QAPs) and information on milk spots was obtained from the pig abattoir based health schemes. Two working datasets were created. The first consisted of 505 farms recruited from the whole of Great Britain (GB). The second combined 338 farms from England and Wales (EW) with housing and feed category-specific information (e.g. for growers and finishers separately), which was not fully available for inclusion in the previous dataset. The variables were studied in multivariable beta-binomial models with the presence of milk spots being the response variable. Solid floor with bedding appeared as a risk factor, OR 1.52 (95% confidence intervals (CI) 1.26-1.85) for the GB sample, and OR 1.47 (CI 1.19-1.81) for the EW subset. Those GB herds that had all the stages of production indoors appeared to be at lower risk of milk spots (OR 0.4, CI 0.32-0.49). Changes were detected within year, with higher risk of milk spots in the second six months of the year OR 1.17 (CI 1.02-1.35) in the GB sample and 1.21 (95% CI 1.04-1.41) in EW farms. Overall this study suggests that those husbandry practices facilitating optimal levels of hygiene posed lower risk of milk spots in slaughtered pigs, potentially reflecting lower levels of ascariosis in the later stages of production.

1 Introduction

Milk spot liver is a well-established terminology used to denote the whitish healing foci occurring in the liver stroma when *Ascaris suum* larvae are immobilized by the host's inflammatory reaction (Kelly, 1993, pp. 375). Ascariosis is the most important internal macro-parasitism present in farmed pigs worldwide (Stewart and Hoyt, 2006, pp. 904-905). A number of economic losses have been attributed to it, including depressed growth rates (Stewart et al., 1996) associated with a decrease in feed conversion efficiency (Stewart and Hale, 1988). Ascariosis may also interfere with the pig immune modulation, having a negative effect on post-vaccination immunity levels against *Mycoplasma hyopneumoniae* (Steenhard et al., 2009). In abattoirs, the presence of milk spots represents considerable losses due to offal condemnations (Barker et al., 1993, pp. 283-285).

It has been reported that housing conditions (i.e. floor type) and management practices (e.g. cleaning and disinfection procedures; type of feeding) play an important role in the development of *Ascaris suum* (Roepstorff and Nansen, 1994; Roepstorff and Jorsal, 1990; Petkevicius et al., 1997). Furthermore seasonal fluctuations in parasite development and in the subsequent presence of milk spots have been reported (Stevenson, 1979; Goodall et al., 1991; Wagner and Polley, 1999). There have been, however, insufficient recent studies to investigate those factors that influence the prevalence and distribution (both temporal and geographical) of the parasite within the current systems of production used by the British pig industry. Infestations under conditions of good hygiene and husbandry are not usually severe enough for the pigs to display clinical signs (Barker et al. 1993, pp. 283-285). Milk spots, if present, tend to occur asymptomatically being incidental post mortem findings at necropsy or abattoir inspections. The presence of *Ascaris suum* – or its lesions – therefore, cannot easily be detected in the live pig. The diagnosis is made either directly (e.g. by faecal egg detection or serology) or indirectly (presence of migration lesions in lung or milk spots in liver). Consequently, carrying out large scale epidemiological studies on ascariosis necessitates significant budgetary and logistic resources.

The British abattoir monitoring health schemes - Wholesome Pigs Scotland (WPS) and British Pig Health Scheme (BPHS) - are implemented by the pig industry. The cornerstone of these schemes is the frequent feed-back of benchmarked results from abattoir inspections to the participating producers increasing their awareness of the occurrence of these subclinical diseases. Health scheme monitoring takes place independently of government abattoir routine meat inspections, which have the principal objective of ensuring food safety. The potential to perform epidemiological analyses using abattoir monitoring reports from the pig health schemes has been exploited for respiratory conditions (Sanchez-Vazquez et al., 2010) and for *Salmonella* seroprevalence (Smith et al., 2011). This is a cost-effective approach allowing for the inclusion of larger and more representative samples. Bernardo et al (1990) evaluated the detection of milk spots in the abattoir as a surveillance tool, finding a good correlation between herds with a high proportion of pigs affected with milk spots and those where intestinal *Ascaris* was more prevalent, although the speed of resolution of lesions means that milk spot lesions observed in the abattoir generally provides information on the *Ascaris suum* challenge in the last four weeks before slaughter (Stewart and Hoyt, 2006, pp. 905).

The aim of this study was to identify those husbandry practices, geographical locations and seasonal patterns that influence the prevalence of milk spots in batches of slaughtered pigs in the Great Britain.

2 Material and Methods

2.1 Data source

Abattoir data on milk spots was extracted from the databases of the two existing pig health schemes in Britain - BPHS and WPS - which provide services in 17 major pig abattoirs. Both schemes aim to obtain a representative sample from each batch of pigs by assessing every other pig on the slaughter line. Milk spot lesions were scored as a binary variable, present or absent, in each assessed pig. The scoring was carried out by swine veterinarians trained in this method of testing on the abattoir inspection line. Different veterinarians carried out assessments in the same abattoir and rotated duties around differing abattoirs to maintain the consistency in meeting the diagnostic criteria.

Farm information was obtained from the three main British farm quality assurance programmes (QAPs): Assured British Pigs (ABP) and Genesis Quality Assurance (GQA) in England and Wales, and Quality Meat Scotland (QMS) in Scotland. The QAPs audit the farms periodically – at least annually – and by means of questionnaires, collect and document a large amount of information on farm production descriptors (e.g. type of housing, type of feeding, number of finishing pigs, number of sows, etc.). Current and historic data available at the commencement of this study and covering the period between September 2005 and September 2007 were used. Farm was defined as a site that had a specific Defra herdmark (Animal Health, England, 2007). This is a unique official reference identifier for each holding consisting of an alphanumeric code also used to identify pigs sent to the abattoir by a tattoo on each shoulder, otherwise known as a slapmark. A batch was defined as a group of pigs from a single farm submitted to the abattoir on a particular date.

2.2 Data management

Two datasets were created for this study. The first included producers belonging to any of the three QAPs with farms from Scotland, England and Wales (referred to as the GB dataset). English-Welsh QAPs hold category-specific housing characteristics and more comprehensive feeding information not present in the Scottish database. Subsequently, for more detailed analyses, a parallel recruitment for a second dataset was carried out only including farms from English-Welsh QAPs (referred to as the EW dataset).

The records available for two years in the QAPs were reviewed for each individual farm to determine its characteristics. Information concerning the stock numbers present at the time of the farm audits and dates when the information was updated were included in the databases. The date of the farm audit was used as a time reference to link husbandry and abattoir data. The other variables (e.g. flooring and housing characteristics, feeding systems), had no specific date attributed to them as they were considered to be farm structural characteristics or management practices, unlikely to change over the study period.

2.2.1 Producing the GB dataset

For the GB dataset, the study population consisted of those pig producers that had pigs assessed by a health scheme and were also part of any of the three QAPs.

Farm variables that were common to the three QAPs, and potential proxys for a risk/protective factor for the occurrence of milk spots in finishing pigs, were identified. The following variables met those criteria: total number of finishing pigs and sows; flooring characteristics of finishing pigs' housing; use of wet-feeding; presence of a breeding unit on site and reported use of outdoors accommodation at any stage of production. Information on these husbandry characteristics was extracted for the GB dataset together with farm specific abattoir information on milk spots for the 12 month period prior to and after the QAP audits. A summary of all the different variables considered in the analysis can be found in Tables 1 and 2. A more detailed explanation on the methodology followed for this process is described in a previous paper (Sanchez-Vazquez et al.; 2011).

Table 1. Categorical farm variables for GB dataset.

Variable	Classes/Level of exposure	Description	Pigs assessed (n)	Pigs positive (%)
		N yes (%)		
Health Scheme where the abattoir scoring data have been reported	BPHS	2108 (80) batches	94,373	3.40
	WPS	542 (20) batches	35,446	6.50
Geographic area where the farm was located	North [(a)]	113 (22) farms	38,169	4.68
	Scotland	166 (33) farms	35,446	6.50
	South East [(b)]	179 (36) farms	38,647	1.66
	South West [(c)]	47 (9) farms	17,557	4.47
Having a breeding herd	Yes	212 (42)	61,885	3.70
	No	293 (58)	67,934	4.75
All production indoors (without records for stages of outdoors production)	Yes	459 (91)	114,576	3.54
	No	46 (9)	15,243	9.55
Use of wet-feeding	Yes	72 (14)	29,597	2.33
	No	433 (86)	100,222	4.82
Use of solid floor with bedding	Yes	393 (78)	91,979	5.13
	No	112 (22)	37,840	2.09
Use of part slatted floor	Yes	98 (19)	36,297	3.70
	No	407 (81)	93,522	4.46
Use of full slatted floor	Yes	128 (25)	51,136	2.21
	No	377 (75)	78,683	5.57

[(a)] North England, York and the Humber.

[(b)] East Midlands, East Anglia and South East.

[(c)] West Midland, Wales and South West.

Table 2. Continuous farm variables studied by classes for GB dataset.

Variable	Classes divisions	Number of farms (%)	Pigs assessed (n)	Pigs positive (%)
Number of finishers present in the farms	More than 9000 finishers	23 (5)	13,918	6.85
	Between 2500 and 9000 finishers	182 (36)	61,221	3.29
	Less than 2500 finishers	300 (59)	54,680	4.66
Number of sows present in the farms	More than 600 sows	28 (6)	13,571	6.83
	Between 150 and 600 sows	145 (28)	46,883	2.35
	Between 15 and 150 sows	31 (6)	4,087	4.11
	None sows present	301 (60)	65,278	5.09

To investigate regional differences in lesion prevalence, Great Britain was divided into four areas (see Figure 1): a) Scotland; b) North England, Yorkshire and the Humber (North); c) East Midlands, East Anglia and South East (South East); d) West Midlands, Wales and South England (South West). Information from the pig industry regarding location of the abattoirs participating in the scheme and of the farms supplying pigs to those abattoirs dictated geographical divisions - a proxy for farm capture areas of the abattoirs.

Figure 1. Map presenting the geographical divisions used to study farm location effect.

2.2.2 Producing the EW dataset

For the EW dataset, the study population consisted of pig producers from English/Welsh QAPs whose pigs were assessed by BPHS. This second database was created following the same methodology as above, including farm characteristics that were common to GQA and ABP. This included housing category-specific information (e.g. for growers, for finishers) and feeding records (on the feed form and on the use of co-product feeds) not available in the GB datasets. A more detailed summary of all the different variables considered in the analysis is presented in Tables 3 and 4. Farm location was not available for 35% of these producers and was therefore not included in the EW dataset.

Table 3. Categorical farm variables for the EW dataset.

Variable	Classes/Level of exposure	Description N yes (%)	Pigs assessed (n)	Pigs positive (%)
Having a breeding herd	Yes	163 (48)	47,948	2.79
	No	175 (52)	57,975	4.54
Outdoors growing taking place in the farm	Yes	20 (6)	7,845	8.31
	No	318 (94)	98,078	3.38
Outdoor finishing taking place in the farm	Yes	5 (2)	1,565	12.91
	No	333 (98)	104,358	3.61
Use of solid floor with bedding	Yes	251 (74)	71,892	4.67
	No	87 (26)	34,031	1.81
Use of part slatted floor	Yes	102 (30)	37,040	3.50
	No	236 (70)	68,883	3.88
Use of full slatted floor	Yes	126 (37)	51,114	1.73
	No	212 (63)	54,809	5.63
Use of wet-feeding in finishing pigs	Yes	66 (20)	30,792	1.36
	No	272 (80)	75,131	4.73
Use of meal in finishing pigs	Yes	99 (30)	27,367	2.33
	No	239 (70)	78,556	4.24
Use of pellets in finishing pigs	Yes	210 (62)	60,872	4.91
	No	128 (38)	45,051	2.18
Use of enzymes in finishers	Yes	114 (34)	36,063	3.06
	No	224 (66)	69,860	4.11
Use of antibiotics in finishers	Yes	94 (28)	29,379	2.75
	No	244 (72)	76,544	4.13
Use of probiotic supplementation	Yes	14 (4)	4,562	1.16
	No	324 (96)	101,361	3.87
Use of non-dairy co-products	Yes	57 (17)	25,319	1.40
	No	281 (83)	80,604	4.49
Use of dairy co-product	Yes	52 (15)	24,951	1.27
	No	286 (85)	80,972	4.51
Use of other dry co-products	Yes	78 (23)	31,205	1.20
	No	260 (77)	74,718	4.81
Restricted feeding in finishers	Yes	34 (10)	9,777	0.64
	No	304 (90)	96,146	4.06

Table 4. Continuous variables studied by classes for the EW dataset.

Variable	Classes divisions	Number of farms (%)	Pigs assessed (n)	Pigs positive (%)
Number of finishers present in the farms	More than 5000 finishers	22 (7)	13,541	4.78
	Between 1500 and 5000 finishers	157 (46)	62,037	2.83
	Less than 1500 finishers	159 (47)	30,345	5.16
Number of sows present in the farms	More than 600 sows	21 (6)	9,857	5.02
	Between 150 and 600 sows	108 (32)	40,591	1.72
	Between 1 and 150 sows	29 (9)	5,076	1.20
	No sows present	180 (53)	50,399	5.39

2.3 Statistical analysis

This investigation aimed to study the risk/protective factors associated with the prevalence of milk spots. The response variable in all our analyses was the presence of milk spots.

Initially, the analysis comprised univariable explorations to investigate the associations between the observed prevalence for milk spots and the different farm factors considered. The variables were tested for correlation. The number of finishing pigs was studied in our model both as continuous and as categorical variables. The number of sows was studied as a categorical variable with the baseline class being no sows present on the farm. The troughs and the inflection points in the density function were used to establish data-derived cut off points to create categories for each of these continuous variables. Monthly, quarterly and six-monthly temporal variations in the prevalence of milk spots were also investigated in the model. A logarithm transformation for the number of finishing pigs was used to ensure robust outputs for this continuous variable in the regression analysis.

The variables were included in a multivariable generalized linear model (GLM) and, through a backward elimination process, were retained in the model if the individual Wald test was considered statistically significant ($p<0.05$). A variance inflation factor was computed to assess collinearity among the predictor variables (Dohoo et al., 2003). The variables retained in our initial multivariable model were included in a mixed effects binomial logistic regression multivariable model. Random effects at the batch, farm and abattoir level were investigated. These initial models assumed a binomial distribution. However, due to a high proportion of pigs with absence of lesions, zero-inflated binomial and beta-binomial models were also considered. A beta-binomial model incorporates beta-distributed random effects and is essentially a model for grouped or replicated data (Dohoo et al., 2003). This approach allows for the potential over-dispersion present in our data due to different levels of clustering (e.g. batch, farm). Once the diagnostics criteria of the model were satisfied, the goodness of fit measurement Akaike's information criterion (AIC) was used to choose the best model from the candidates. Additionally, substantial changes in the estimated coefficients in the models and increases in standard errors during the model building process were investigated. Biologically plausible interactions between the variables present in the final model were investigated using likelihood ratio tests. All the analyses were performed in R (R Development Core Team, 2005) using libraries stats, lme4 and vgam.

3 Results

The models that provided the best goodness of fit to the data were those using a beta-binomial distribution. Results are presented in Tables 5 and 6 and summarised in the following two sections. The overall prevalence for the GB dataset was 4.4% of pigs affected with milk spots; while the percentage of farms with at least one pig affected with milk spots was 67%. For the EW subsets, milk spot pig prevalence was 3.7% from 71.9% of the farms.

Table 5. Estimated odds ratios in the multivariable beta-binomial model including variables associated with presence of milk spots in finishing pigs. For GB dataset. N=505 farms.

Farm variable	Level	Odds ratio	95% CI
Solid floor with bedding	Yes	1.52	1.26 - 1.85
	No	1.00	-
Wet-feeding	Yes	0.52	0.42 - 0.64
	No	1.00	-
Breeding herd on the unit	Yes	0.67	0.57 - 0.78
	No	1.00	-
All production Indoors	Yes	0.40	0.32 - 0.49
	No	1.00	-
Area	North [(a)]	1.96	1.62 – 2.37
	Scotland	2.63	2.15 - 3.21
	South West [(b)]	2.62	2.07 - 3.32
	South East [(c)]	1.00	-
Six month period	Second six months of the year	1.17	1.02 - 1.35
	First six months of the year	1.00	-

[(a)] North England, York and the Humber
[(b)] West Midland, Wales and South West England
[(c)] East Midlands, East Anglia and South East

Table 6. Estimated odds ratios in the multivariable beta-binomial model including variables associated with presence of milk spots in finishing pigs. For the EW dataset. N=338 farms.

Farm variable	Level	Odds ratio	95% CI
Solid floor with bedding	Yes	1.47	1.19 - 1.81
	No	1.00	-
Full slats	Yes	0.72	0.59 - 0.87
	No	1.00	-
Feeding pellets in finishers	Yes	1.33	1.12 - 1.57
	No	1.00	-
Probiotics in finishers	Yes	0.62	0.39 - 0.99
	No	1.00	-
Breeding herd on the unit	Yes	0.73	0.61 - 0.87
	No	1.00	-
Outdoors growing	Yes	1.73	1.34 - 2.23
	No	1.00	-
Farm size	Small (less than 1500 finishers)	0.66	0.51 - 0.86
	Medium (from1500 to 5000 finishers)	0.71	0.55 - 0.89
	Large (more than 5000 finishers)	1.00	-
Six month period	Second six months of the year	1.21	1.04 - 1.41
	First six months of the year	1.00	-

3.1 Results from the analyses on the GB dataset

This dataset held QA information from 505 farms. This included records from 2,650 batches assessed through the health schemes; corresponding to a mean of 5 batches per farm (median 4) with a standard deviation (σ) of 4.62 (Quartile (Q)1 2 and Q3 7). These assessments integrated a total of 129,819 pigs inspected, with a mean of 49 pigs per batch (median 50) and σ of 28 (Q1 40 and Q3 50).

Geographical location had the highest estimated odds ratios of all the variables studied; the odds of a slaughtered pig from Scotland being reported as having milk spots was more than twice the odds for a pig from the South East. The other regions investigated, i.e. North England and South England, also presented a higher risk compared with the observed prevalence in the South East.

A mild but significant positive association with milk spots was observed for those farms having finishing buildings constructed with solid floor and using bedding compared to those not having this type of floor. Those farms with a wet-feeding system for finishing pigs had a lower risk of milk spots than those using dry feed. Farms that had a breeding herd had a lower risk of milk spots than those farms registered as just finishing units. A smaller risk of milk spots was detected in farms where all the production cycle was indoors compared with those farms which reported production stages outdoors.

The period of the year was a significantly associated factor in our final model with a slightly higher risk of milk spots present in the second half of the year, compared to the first half of the year (the baseline).

3.2 Results from the analyses on the EW dataset

This dataset included QA information from 338 farms. This included records from 2,463 batches of pigs assessed by BPHS with a mean of 7 batches per farm (median 6) and σ 5.53 (Q1 3 and

Q3 10). These assessments integrated a total of 105,923 pigs inspected with a mean of 43 pigs per batch (median 50) and σ of 12 (Q1 40 and Q3 50).

A higher risk of milk spots was detected in those farms where outdoor growing took place compared with those farms with an indoor growing system. A weak but significant positive association with milk spots was observed for those farms having finishing buildings constructed with solid floors and using bedding, whereas a slightly reduced risk of milk spots was detected for those farms using fully slatted floors compared to those not having this type of floor.

There was a weak but significant positive association with milk spots for those farms feeding finishers with pellets when compared to those farms not employing this feed form. The utilization of probiotics in finishing pigs was associated with a lower risk of milk spots.

Farms that had a breeding herd had a slightly lower risk of milk spots. A slightly lower risk of milk spots was also detected in medium (from 1,500 to 5,000 finishers) and small (less than 1,500 finishers) size farms compared to the large ones (over 5,000 finishers).

There is an association of the period of the year with the prevalence of milk spots. The risk of milk spots was slightly higher in the second half of the year when compared to the first half of the year.

4 Discussion

This study has identified husbandry practices, geographical locations and seasonal patterns that are associated with the prevalence of milk spots in batches of slaughtered pigs. The lifespan of the milk spot lesions may pose some restrictions in the interpretation of these findings as they tend to disappear within 25 days (Stewart and Hoyt, 2006, pp. 905). The results presented in this paper would, in the main, be reflecting evidence of recent within herd parasite transmission in the slaughtered pigs.

4.1 Area

The farm location appears to be an important predictor for the prevalence of milk spots. Slaughtered pigs from North England, Scotland and South West England seem to be at a higher risk of milk spots than those pigs finished in the South East of England. *Ascaris suum* is highly ubiquitous and likely to be present in all herds. Roepstorff and Nansen (1994), acknowledged the fact that it had proven to be difficult to find herds that could be declared totally free from this ascarid. The regional differences in milk spots prevalence found in this study are therefore perhaps more likely to be due to differences in the husbandry practices focused on controlling within farm *Ascaris suum* transmission, rather than to genuine regional differences in the presence or absence of the parasite. These findings may also be an effect of any large production enterprises and veterinary practices found within a region and the impact of their respective general health programmes - particularly regarding recommended deworming, cleaning and disinfection protocols - on the overall health status of the region. It can be argued that the regional differences detected in the risk of milk spots could be attributed to misclassification bias in the abattoir assessments. However, the health schemes operate quality control systems to maintain consistency in scoring and the veterinarians rotate among different abattoirs.

4.2 Farm characteristics

Solid floors with bedding appear to be a consistent risk factor for higher prevalence of milk spots whereas the use of full slats seems to be protective. The use of bedding material may hamper the effectiveness in destruction of the *Ascaris suum* eggs by routine cleaning and disinfection protocols. Pigs reared in this system have greater contact with faeces, facilitating faecal-oral parasite transmission, than those pigs on slatted floors, particularly fully-slatted. A previous study identified the use of bedding as risk factor for *Ascaris suum* infection in sows (Dangolla et al., 1996). Other authors have also reported that those farms where bedding was used had a greater proportion of sows and fatteners affected with *Ascaris suum* than those farms not using bedding and/or having slatted floors (Roepstorf and Jorsal, 1990). Dangolla et al (1996), explained that bedding might provide a protective environment for the parasite eggs which help them to survive longer and develop to infective stages. This scenario, in our study, might have led to greater ascarid transmission in finishing pigs reflected in more livers becoming affected with milk spots.

In the first set of analyses, on the GB dataset, those herds that have reported all phases of production to be indoors had a lower risk of milk spots compared to those that have some stage of the production cycle outdoors. This finding has been discussed previously (Roepstroff and Nansen, 1994) with the conclusion that, although *Ascaris suum* is capable of completing its life cycle indoors, the higher hygiene standards in housed production result in fewer viable parasites present in indoor production than in extensive conditions. Investigated in more detail in the EW dataset, it appeared that there was a higher risk of milk spots for those farms with outdoor growing pigs - the age period that coincides with the peak of *Ascaris suum* infection (Nansen and Roepstorff; 1999). These results indicate major parasite egg pressure in the later stages of outdoor production – i.e. growing and finishing. Outdoor production within the British pig industry is an expanding husbandry practice in response to an increasing demand for free-range pork. Therefore, our results have notable relevance for the industry indicating that particular attention needs to be paid to helminth control in this phase of the production system.

Those units using liquid feeding appeared to be at lower risk for the presence of milk spots. This could be related to the overall benefits of wet-feeding on the intestinal lumen environment and by favouring the processes involved in digestion (Gill; 2007). Investigating the effect of the type of feeding more specifically, we found that there was a higher risk of milk spot livers on farms using pelleted feed. This could be related to the level and chemical form of non-starch polysaccharides (NSPs) present in this processed feed form, as the pelleting process could have modified the NSPs and the gut environment. It has been reported that dietary composition affects the development of intestinal parasites such as *Oesophagostomum dentatum*, with higher levels of dietary fibre promoting parasite proliferation (Petkevicius et al.; 1997). In the same way, we can speculate that probiotics may modify the intestinal lumen environment, hampering parasite establishment, perhaps explaining the potential protective effect identified. However, it is also possible that these findings might not necessarily reflect the direct effect of diet (i.e. liquid feeding, use of pellets, use of probiotics) but may be an indicator for other features of production (e.g. better effort at managing their parasite control; more intensive production; specific environmental control) which influence *Ascaris suum* transmission, at least in the later stages of production.

Herds with a larger number of finishing pigs on site appear to have a higher risk of milk spots as has also been reported for Danish sow herds (Dangolla et al., 1996). Our findings may reflect the presence of a more hygienic environment that limits the within-herd transmission; and/or more efficient deworming protocols in small/medium size herds. Gardner et al (2002) - focussing on respiratory problems - specifically discussed the role of herd size as a potential risk factor for pig diseases. Herd size may be related to various risk factors such as introducing infectious agents from outside the herd (e.g. with carrier pigs) and increased transmission of infectious agents within large herds. These authors also discussed the presence of management factors that are associated with herd size (e.g. production system, disease control practices, labour structure and organization). Thus, herd size may be a proxy for other correlated factors not available in our study. Alternatively, high stocking densities increase the levels of gastrointestinal parasites (Thomsen et al., 2001). Potentially, this could have contributed to the association detected between number of finishers and evidence of ascarid transmission. However, in the experience of the authors the stocking densities do not necessarily correlate with herd size in the British pig industry. This is partially due to the implementation of a maximum legal stocking rate across all the pig farms, irrespective of their sizes.

4.3 Breeding animals present in the unit

The presence of breeding animals within the unit appeared to be a potential protective factor for the presence of milk spots in finishing pigs. Those units that produce their own stock may have deworming protocols (e.g. pre-farrowing) and strategies to keep weaners and finishers away from the areas potentially contaminated with ascarid eggs. Additionally, the presence of breeding animals on site indicates farrowing-to-finish rather than a multisite system where there may be more mixing of sources which could lead to increase helminth prevalences (Joachim et al., 2001). Furthermore breeding herds may have developed immunity levels over the years that help to reduce the prevalence of adults affected with *Ascaris suum* and the severity of the infection contributing to a lesser egg load in the units overall.

4.4 Seasonal variation

There was a significant difference in the risk of milk spots in the first and second half of the year. The combined period for the first six months had a lower risk of milk spots compared with the second half of the year. A similar temporal distribution was reported for the detection of milk spots in pigs slaughtered in Northern Irish abattoirs, with lesion peaks detected in summer and autumn (Gooddall et al., 1991). These authors found a good correlation between the temperature in spring and early summer and the prevalence of milk spots. Previous studies have also observed these seasonal variations in the development of the *Ascaris suum* eggs associated with changes in the temperature of pig barns (Stevenson, 1979; Warner and Polley, 1999; Joachim et al., 2001).

4.5 Further constraints and discussion

The sample of farms included in this study is considered to be representative of the population of assured (professional) British pig producers. Most of the associations reported in these analyses (excepting the ones related to location and the use of indoor production), although robust, were weak associations (odds ratios close to one) suggesting that only marginal differences exist between exposed and unexposed groups. The large sample size of this study (505 and 338 farms) would have helped to detect such associations.

Our study relied upon abattoir findings of milks spots as a proxy for detection of ascariosis. Bernardo et al (1990), inferred that abattoir liver monitoring could provide satisfactory farm level classification for *Ascaris suum* parasitism. This finding is in line with the methodology followed in our study which included several batches of pigs per farm, aiming to optimise the adequate classification of the farms with this sample recruitment.

The use of information from existing databases also harbours some potential drawbacks. The datasets may have contained flaws for some of the QAPs records (e.g. the presence of unrecorded changes over time in some of the farm characteristics; inconsistent recording of the farm characteristics) which could have introduced misclassification bias. It was assumed, however, that these errors had no differential bias and would be equally present in either the exposed or the unexposed group (when considering the farm factors studied) regardless of the prevalence of these conditions. Moreover, to minimise this problem, this study did not rely on the information collected on just one farm audit but also has reviewed and contrasted the historical information which was thus included in the combined database used for the analyses.

An important limitation in this study was the lack of information on other variables that play a role in predicting the occurrence of the Ascariosis and/or the parasite transmission: the anthelminthic treatment regimes, the protocols for cleaning and disinfection; pig age category management and other husbandry practices. This situation may have led to a potential clustering of the observations at batch or farm level. The statistical approach used for the analyses (GLM with beta-binomial distribution) would have helped to account for unknown herd specific management factors.

4.6 Conclusion and future actions

Overall, this study suggests that those husbandry practices that were more in line with maintaining optimal protocols of hygiene and disinfection (e.g. indoor production, no use of bedding) posed lower risk of milk spots, potentially reflecting a lower level of ascarid transmission in the last stage of production. Particular attention must be paid to helminth control in outdoor and straw-bedded production systems, both of which are expanding in response to an increasing consumer demand for free-range pork. In addition, our findings have shown that, despite the current methods of production, *Ascaris suum* burdens still show within-year variation. This finding is an important feature to be considered in establishing the optimal timing of deworming intervention. This study was the first attempt at combining existing information from the British pig industry to perform large-scale epidemiological studies to investigate the occurrence of milk spots and these outputs may serve as a baseline for future studies on pig disease prevention and control in Great Britain.

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Chapter V

Using seasonal-trend decomposition based on loess (STL) to explore temporal patterns of pneumonic lesions in finishing pigs slaughtered in England, 2005-2011

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Abstract

Enzootic pneumonia (EP) is responsible for considerable economic losses in pig production. This study analyses temporal variations of pneumonic lesions present in slaughtered finishing pigs utilising a novel analytical tool – STL decomposition. Using data collected over a six-year period starting in July 2005, time-series analyses were conducted to identify trend and the presence of seasonal variations to support industry led measures to monitor and control this important respiratory disease. In England, the BPEX Pig Health Scheme monitors the occurrence of EP in slaughtered finished pigs by identifying its gross pathology, enzootic pneumonia-like (EP-like) lesions. For visual analytics, the monthly prevalence for EP-like lesions was modelled using STL, a seasonal-trend decomposition method based on locally-weighted regression. A binomial generalised linear mixed-effects model (GLMM), accounting for clustering at batch level, was used to test the significance of the trend and seasonality. A mean of 12,370 pigs was assessed per month across 12 pig abattoirs over the study period. A trend toward reduction in prevalence of EP-like lesions during the first three years of BPHS, followed by an increasing trend, was identified with STL. This feature was consistent with the presence of a statistically significant positive quadratic term ("U" shape) as identified using the GLMM inference model. November and December appeared in the STL explorations as higher seasonal peaks of the occurrence of EP-like lesions. These two months had a significantly higher risk of this disease (OR = 1.38, 95% CI: 1.24 - 1.54 and OR = 1.4, 95% CI: 1.25 - 1.58, respectively, with July taken as baseline). The results were reported back to the pig industry as part of the national monitoring investigations.

1 Introduction

Respiratory disorders are regarded as the most serious diseases in modern swine production world-wide (Sorensen et al., 2006). Particularly in Great Britain, enzootic pneumonia-like (EP-like) lesions have been reported as the most prevalent respiratory condition detected through pig abattoir monitoring (Sanchez-Vazquez et al., 2010a). Although EP-like lesions are not pathognomonic for a particular pathogen (Sibila et al., 2009), *Mycoplasma hyopneumoniae* is usually involved in this pathology (Sorensen et al., 2006; Meyns et al., 2011). Substantial economic losses have been attributed to this infection including reduced feed efficiency, reduced daily weight gain and increased production costs due to medication (Straw et al., 1989; Thacker, 2006). Since 2005 the BPEX Pig Health Scheme (BPHS) has monitored the occurrence of respiratory gross pathology in pigs slaughtered in England's main pig abattoirs. On a regular basis, swine veterinarians carry out detailed post-mortem examinations in parallel to the routine official food-safety meat inspections. BPHS offers consistent monitoring of the occurrence of EP-like lesions, which is used by the pig industry to evaluate the behaviour of national trends and to promote strategies leading to health recommendations aimed at addressing increasing trends, or to confirm favourable situations when the level of a disease is diminishing.

Understanding the temporal patterns of a disease is an essential step in learning about its epidemiology. Time-series analyses aim to provide a concise description of data correlated through time – serial correlation. Exploratory methods and graphical representations are integral to understanding the complexity of serially correlated data (Diggle, 1990). This is particularly true where the sample is equivalent to the population or a large sample size is available (where, for most practical purposes, the sample behaves approximately equal to the population), in which statistical inference is secondary in favour of descriptive methods. In this respect BPHS, with six years of consistent monitoring in English abattoirs, offers a unique opportunity to explore the temporal patterns of the occurrence of EP-like lesions. An exploratory method well-established in other fields is a seasonal-trend decomposition based on locally-weighted regression (loess) widely known as "STL" (Cleveland et al., 1990; Hafen et al., 2009). The STL method is straightforward to use, allows for flexibility in specifying the amount of variation in the trend and seasonal components of time-series, and produces robust estimates that are not distorted by transient outliers (Cleveland et al., 1990). In particular STL offers excellent data visualization – visual analytics – (Hafen et al., 2009). STL has been widely used in several disciplines including environmental science, ecology, epidemiology and public-health (Cleveland et al., 1990; Chaloupka, 2001; Silawan et al., 2008; Hafen et al., 2009).

This study analyses the six year trend of BPHS EP-like lesions and identifies the presence of seasonal variations, thereby investigating the progress (if any) made by the industry in controlling this respiratory disease. This paper presents a time-series investigation executed in two steps: firstly, visual analytics through STL are utilised to explore the temporal structure of this respiratory pathology; and secondly, an inference model, generalised linear mixed model (GLMM), is used to statistically test the significance of the temporal attributes. This paper is also intended as a reminder of the importance of data exploration in time-series analyses, and therefore places a particular emphasis on describing the graphical exploratory process executed with STL.

2 Material and Methods

2.1 Data source

2.1.1 BPEX Pig Health Scheme

BPHS has monitored the occurrence of EP-like lesions across the largest pig abattoirs in England since July 2005. Veterinarians assess every second pig in a batch (up to fifty pigs assessed) for gross pathology. The scheme feeds back benchmarked results from abattoir inspections to the participating producers (i.e. those paying a fee to be part of the scheme). The inspections, however, include all the batches submitted to the abattoir on the assessment days regardless of their BPHS membership status. More detailed information about BPHS can be found elsewhere (Sanchez-Vazquez et al., 2011).

2.1.2 Study sample

This study used all (members and non-members) BPHS records available from the 12 abattoirs that participated in BPHS from July 2005 to June 2011. The abattoirs are geographically wide-spread across England (see Figure 1). A total of 890,654 pigs (from 20,874 batches) has been assessed over this six-year period, submitted from 1,541 herds. The study data are the combined set of pigs assessed by BPHS.

Figure 1. Map of Great Britain showing England shaded, with dots representing the location of the 12 abattoirs included in the study.

2.1.3 The EP-like lesion

EP-like lesions are reported for the following gross pathology: a red-tan-grey discoloration, collapse, and rubbery firmness affecting cranioventral regions of the lungs in a lobular pattern (Caswell and Williams, 2007). The lungs of every pig inspected were given a score that represents the approximate percentage of the parenchyma consolidated on a scale from 0 to 55. Because the aim of this study was to investigate the occurrence of EP-like lesions, a positive case was defined as a pig affected with any degree of lesion (score >0) and a negative when lesions were absent (score =0). This criterion has been used before to investigate risk factors associated with EP-like lesions (Sanchez-Vazquez et al., 2010a).

2.2 Modelling

2.2.1 Time-series data

The time-series was composed of monthly prevalence estimates, computed as the number of pigs affected with EP-like lesions, divided by the number of pigs assessed. The seasonal cycle was studied yearly (12 months), and for the seasonal cycle subseries comprised the set of observations for a particular month across the six years (e.g. all the values for July, all the values for August, and so on).

2.2.2 Visual analytics, STL

STL was utilized to model the EP-like lesions time-series of monthly prevalences. STL is a filtering procedure for decomposing a time-series into additive components of variation (trend, seasonality and the remainder) by the application of loess smoothing models (Cleveland et al., 1990; Chaloupka, 2001). Six parameters determine the degree of smoothing in the trend and seasonal components (Cleveland et al., 1990):

- n_p - the number of observations in each seasonal cycle.

- n_i - the number of loess smoothing iterations to update the trend and seasonal components (usually set to equal one or two).
- n_o- the number of robustness iterations. With a value of zero no robustness iteration is applied whilst values of one or more apply increasing robustness, particularly above 5. This parameter is chosen in combination with n_i.
- n_l - the span of the loess window for each subseries; it is recommended to use the next odd number to n_p.
- n_s - the span of loess window for seasonal extraction. Low values (e.g. from 7 to 10) favour the use of local data while higher figures pool values from the equivalent time of the year across the time-series.
- n_t - the span of the loess window for trend extraction, typically computed as $[1.5n_p/(1-1.5n_s^{-1})]$.

The adequacy of the model fit was assessed by four graphical diagnostic methods: (1) the decomposition plot; (2) the trend-diagnostic plot; (3) the seasonal cycle subseries plot; and (4) the seasonal-diagnostic plot. Following Cleveland et al. (1990) and Jiang et al. (2010), a number of models were constructed using different parameter values and assessing the results against the diagnostic plots. Further information on the method and parameters can be found in the original paper describing the STL method (Cleveland et al., 1990). The need for data transformation was evaluated utilizing normal quantile plots of the residuals, ensuring its distribution is well approximated by the normal distribution (Hafen et al., 2009). Additionally, marginal residuals plots as described by Fraccaro et al. (2000) were investigated to identify any pattern that could be of concern.

2.2.3 Statistical inference, GLM/GLMM

Batch EP-like lesions prevalence was modelled against time in monthly intervals. The ranges of season variables influencing the prevalence considered were monthly, quarterly and six-monthly. BPHS membership status and abattoir were also examined as covariates to account for their potential confounding effect. A simple binomial model, GLM, was used as a starting point; this evolved into a binomial generalised linear mixed-effects model (GLMM). In this latter model clustering at batch level, farm level, and both farm and batch were examined. Time was modelled as a polynomial function to allow for flexibility beyond a simple linear relationship, according to the findings observed in the visual analytics. The goodness of fit metric, Akaike's Information Criterion (AIC), was used for comparison among the different model structures and also to compare nested models through a stepwise selection process of covariates. The Wald tests were used to examine and present the significance (p value <0.05) of the variables retained in the final model, particularly for those with multiple categories (i.e. month, abattoir). Residual diagnostic plots were used to detect features of concern in the model and to identify the presence of potential outliers. The purpose of the inferential models was to confirm major trends picked up by STL and therefore only main effects were considered. All the analyses and graphs were performed using the R statistical software environment (R Development Core Team, 2009) using the libraries stats, epicalc and lme4.

3 Results

The mean number of pigs assessed per month was 12,370 pigs (95% CI: 11,793 – 12,947), with a mean of 290 batches (95% CI: 276 – 304). Of those, the monthly mean number of pigs from BPHS members was 7,086 pigs (95% CI: 6,692 – 7,480) with a mean of 159 batches (95% CI: 150 – 168). A total of 252,941 pigs (from 18,387 batches) was affected with EP-like lesions across the whole study period which represent 28.4% of the total pigs inspected (28.7% of the members and 27.9% of non-members).

3.1 Results from the STL explorations

Three of the parameters, n_s, n_i and n_o, required tuning through the use of the graphical diagnostic methods. For n_s 7 months was chosen, for n_i and n_o a robust option was chosen being 1 and 5 respectively. The other three parameters were predefined following the recommendations from Cleveland et al. (1990), being n_p=12 months, n_l=13 months and n_t=23 months.

The STL fitted trend was observed in the decomposition plot (Figure 2a) in comparison with the raw data. It shows a decline in prevalence between 2006 and 2008; falling from 34% of the pigs affected to 27%, after which it started to increase reaching 30% in June 2011. In the trend-diagnostic plot (Figure 3a) the trend is compared with the remainder, in graph (b) the two longest vertical lines in the remainder, one in March 2006 and other in December 2007, appear as outliers.

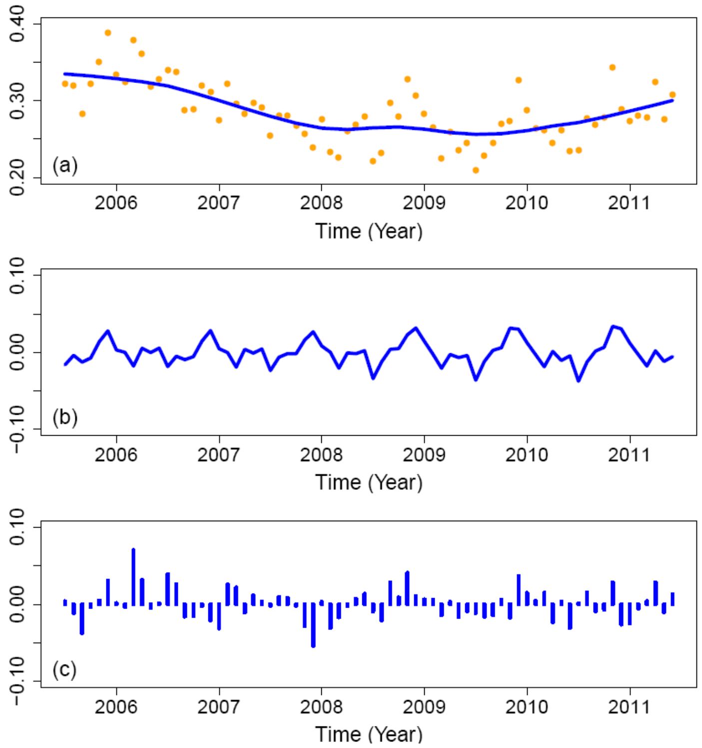

Figure 2. Decomposition plot of the prevalence of pigs affected with EP-like lesions in 12 English abattoirs (2005-2011), STL method. This plot assists evaluation of the trend, seasonality and remainder against the raw data. In the graph (a), the dots represent the monthly time-series for the proportion of pigs affected with EP-like lesions and the line is the STL fitted trend. The graph (b) is the STL seasonal pattern per 12 months. The values on 0 indicate no seasonal variation, as 0 represents an inflection point across the STL extracted trend; anything over 0 indicates increasing seasonal pattern (i.e. above trend) in the proportion of EP-like lesions and below 0 indicates decrease (i.e. below trend). The graph (c) represents the remainder after the trend and the seasonal pattern have been fitted to the time-series values. The sum of the trend, the seasonal pattern and the remainder equals exactly the time-series (dots in the panel (a)). The units in the vertical axis represent the proportion of pigs affected with EP-like lesions.

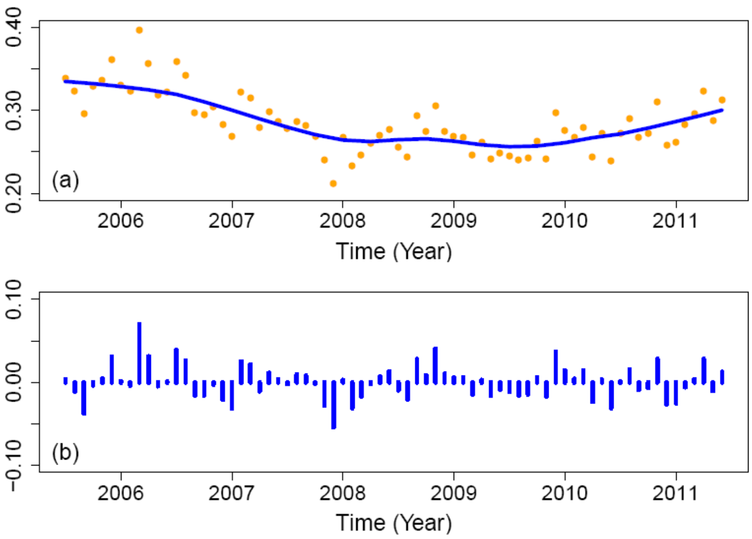

Figure 3. Trend-diagnostic plot of the prevalence of pigs affected with EP-like lesions in 12 English abattoirs (2005-2011), STL method. This plot assists to assess the fit of the trend to the data, which evaluates how much variation in the data other than seasonality goes into the trend and how much goes into the remainder - particularly useful for investigating the effect of the outliers on the trend. In panel (a) the points represent the STL fitted trend plus the remainder and the line is the STL trend. The panel (b) represents the remainder. The units in the vertical axis represent the proportion of pigs affected with EP-like lesions.

The STL seasonal component observed in the decomposition plot (Figure 2b) suggests an increase of EP-like lesions in November-December, and a main drop in July. It also shows variation across years, with the seasonality being more marked over the last three seasonal cycles for most of the months. This interannual variation is more obvious in the seasonal cycle subseries plot (Figure 4), where particularly for July and November, it is possible to appreciate the yearly seasonal values becoming more distant from 0 on the last three seasonal cycles. The seasonal diagnostic plot (Figure 5) compares the fitted monthly values within the cycle subseries for each year with the remainder. This suggests the seasonal smoothing is robust to more outlying observations such as March 2006 and December 2007.

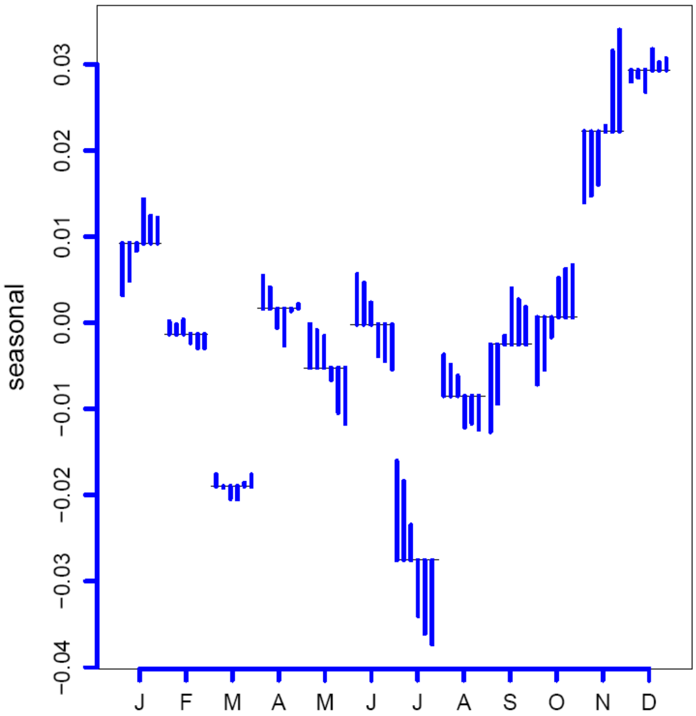

Figure 4. Seasonal cycle subseries plot of the prevalence of pigs affected with EP-like lesions in 12 English abattoirs (2005-2011), STL method. This plot assists in assessing dispersion of each value of the cycle subseries against their mean; thus providing an assessment of the historical seasonal pattern as well as the temporal behaviour of each monthly subseries. Each cycle subseries is graphed separately against years (from 2005 to 2011); the month for each cycle subseries being indicated by its initial in the horizontal axis. The horizontal line is the mean of the STL fitted monthly values for each cycle subseries (values from Figure 2 graph (b)). The fitted values (ends of vertical lines) in relation to the mean show the pattern of the interannual variation of the monthly subseries. The units in the vertical axis represent the proportion of pigs affected with EP-like lesions.

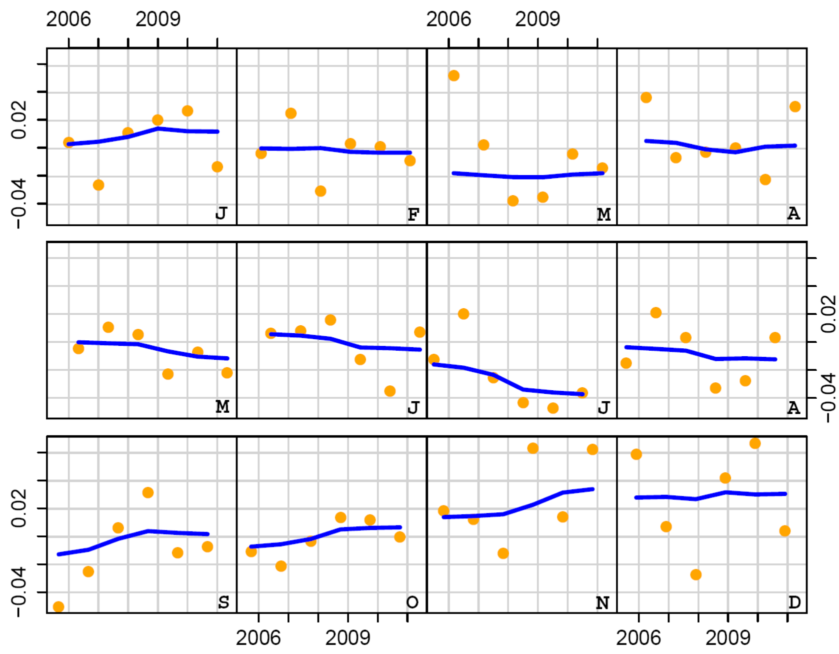

Figure 5. Seasonal-diagnostic plot of the prevalence of pigs affected with EP-like lesions in 12 English abattoirs (2005-2011), STL method. This plot assists in assessing loess regression fit to the month across each year, evaluating how much variation in the data other than trend goes into the seasonal component and how much into the remainder. This plot helps to assess how the presence of outliers or transitional values with aberrant behaviour influences the results of the seasonal component. Each box represents a monthly subseries starting with January in the top left and progressing from left to right and from the top to the bottom. The initial for each month is used to identify the month in each box. The dots represent the STL fitted monthly values within the cycle subseries for each year, plus the remainder. The lines represent the STL fitted monthly values within the cycle subseries for each year. The units in the vertical axis represent the proportion of pigs affected with EP-like lesions.

3.2 Results from the GLM/GLMM testing

The model allowing for clustering in the data at batch level was the model that provided the best fit to the data. A quadratic term for trend (measured in monthly intervals) gave a better fit to the data (AIC=76,129) than a linear relationship (AIC=76,237). The results for the final multivariable GLMM are presented in Table 1. The estimated coefficient defining the quadratic term (16.37, 95% CI: 13.06 - 19.68) indicates that the trend for EP-like lesions followed a "U" shape.

Compared to July (the month with the lowest prevalence acting as baseline), November and December had a significantly higher risk of EP-like lesions (OR = 1.38, 95% CI: 1.24 - 1.54 and OR = 1.4, 95% CI: 1.25 - 1.58, respectively). There were weak but significant differences between members and non-members, with non-members having a lower prevalence of EP-like lesions over the period studied, (OR = 0.94, 95% CI: 0.89 - 0.98). The inclusion of abattoir in the model improved the model fit, indicating significant differences in the risk of EP-like lesions between the different abattoirs compared to abattoir “A” that was taken as the baseline. Exploratory analyses of the residuals suggest that the chosen model was not inappropriate for the data.

Table 1. Estimated coefficients for the linear and quadratic terms fitted to the temporal trend and estimated odds ratios for the covariates in the multivariable binomial generalized linear mixed-effects model for the prevalence of EP-like lesions in finishing pigs slaughtered in English abattoirs accounting for clustering at batch level, 2005-2011.

Variable For random effects	Variance		Standard error of variance component	
Batch	2.42		1.56	
Variables For fixed effects	**Level**	**Estimate/ Odds ratio**	**95% confidence intervals**	**P-value**
	Linear term	-16.18‡	-19.54, -12.82	<0.001
Trend	Quadratic term	16.37‡	13.06, 19.68	<0.001
Month	July (baseline)	1	-	-
	August	1.12 Ŧ	1.01, 1.25	0.04
	September	1.14 Ŧ	1.02, 1.27	0.017
	October	1.17 Ŧ	1.05, 1.29	0.004
	November	1.38 Ŧ	1.24, 1.54	<0.001
	December	1.4 Ŧ	1.25, 1.58	<0.001
	January	1.28 Ŧ	1.15, 1.43	<0.001
	February	1.27 Ŧ	1.14, 1.42	<0.001
	March	1.16 Ŧ	1.04, 1.3	0.007
	April	1.27 Ŧ	1.14, 1.42	<0.001
	May	1.21Ŧ	1.08, 1.35	0.001
	June	1.19 Ŧ	1.07, 1.33	0.002
Being a BPHS member	Member (baseline)	1 Ŧ	-	-
	Non-member	0.94 Ŧ	0.89, 0.98	0.005
Abattoir	A (baseline)	1	-	-
	B	0.98 Ŧ	0.85, 1.14	0.818
	C	0.55 Ŧ	0.51, 0.61	<0.001
	D	0.44 Ŧ	0.35, 0.55	<0.001
	E	0.31 Ŧ	0.27, 0.35	<0.001
	F	0.34 Ŧ	0.31, 0.37	<0.001
	G	0.56 Ŧ	0.51, 0.61	<0.001
	H	0.6 Ŧ	0.53, 0.69	<0.001
	I	0.43 Ŧ	0.37, 0.5	<0.001
	J	0.66Ŧ	0.59, 0.74	<0.001
	K	0.4 Ŧ	0.36, 0.44	<0.001
	L	0.71 Ŧ	0.64, 0.78	<0.001

Model based in a sample of 890,654 pigs from 20,874 batches.

‡ Estimated coefficients for the linear and quadratic term (U shape) for EP like lesion trend.
Ŧ Odds ratios.

4 Discussion

This study has utilised the STL methodology to robustly identify the six year trend and seasonal pattern for EP-like lesions in finishing pigs in England. The data source was the BPEX Pig Health Scheme, which offered a large sample size of consistent abattoir monitoring providing a suitable opportunity to explore temporal patterns. By utilising STL, this paper maintains transparency in the explorations to identify the sources of variation in the time-series (i.e. the trend, the seasonality and a remainder). Both STL and GLMM results are consistent; thus, the inferential statistical testing assisted in confirming the findings from the exploratory process.

4.1 The trend and seasonality

The GLMM identified a significant quadratic trend, which was described by STL as a decline in the occurrence of EP-like lesions between 2006 and 2008 (the first three years of BPHS), followed by a period of increasing prevalence. The occurrence of EP-like lesions results in important economic losses for the industry, particularly due to the worsening in feed efficiency and mean daily gain as a result of pigs being affected by EP (Straw et al., 1989; Straw et al., 1990). The initial prevalence reduction detected could, in principle, be attributed to the impact of the scheme on the overall health of the pig units. Veterinarians reacted to the feedback received for the prevalence of EP-like lesions, implementing measures to reduce it. These measures were conceivably extended to BPHS non-member herds, as has been discussed before (Sanchez-Vazquez et al., 2011). Moreover, non-members appear to have maintained a slightly lower level of disease than members. This apparently paradoxical situation could be also explained by the reluctance of some breeding units to join the scheme since they have their own abattoir monitoring system for respiratory diseases, and such herds are normally in good health and EP free. The reason behind the increasing trend over the last three years (which also corresponded to a more marked seasonal pattern) is unclear, but it could reflect a relaxation in the use of *M.*

hyopneumoniae vaccines. The results from this study were fed back to the industry board, whose role it is to inform field veterinarians and producers of the current situation.

This STL investigation chose a small value to define the span of loess window seasonal extraction to allow for flexibility in the seasonality explorations for each year, rather than pooling the values for the same month across years, which could have potentially distorted the patterns (Hafen et al., 2009). The STL and GLMM results show the prevalence of EP-like lesions increasing at the end of the year (November and December) and declining in summer (July), a trend particularly obvious over the last three years. This pattern is consistent with that reported in most of the previous studies (Elbers et al., 1992; Stark, 2000) and that which has been observed in the syndromic surveillance of English growers and weaners (NADIS, 2008). Given that the life-span of EP lesions is at least two months, and that it could be detected as early as two weeks after infection (Caswell and Williams, 2007), the November-December peaks may be reflecting farm challenges occurring across the whole autumn (from September to December). Done (1991) explained how housed pigs may have poorer air quality due to reduced housing ventilation over colder months in the trade-off for maintaining the indoor temperatures; a practice which may lead to an increase in the incidence of pneumonia.

4.2 STL in the context of time-series analyses techniques

Time-series analyses, particularly those focussed on seasonal-trend decomposition, are scarce in the veterinary literature. Three of the most typical methodologies for which examples in the veterinary field can be found are: (1) moving average (MA) models (Arc Moretti et al., 2010), (2) generalised additive models (GAM) (Jore et al., 2010), and (3) linear regression (and its generalizations (GLM)) (Ward, 2002). MA is probably the simplest statistical technique available for decomposing time-series, and among these three techniques, is the only one directly comparable to STL as they are both filtering procedures. In MA, the filtered value is the averaged results within a predefined slide time-window producing a series of subsets with averaged values.

In STL, the loess iterations are regulated by predefined parameters allowing the model to account for several factors (e.g. robustness, smoothing), offering more flexibility than MA models and providing a better fit to the data. The GLM and GAM belong to a different group of analytic techniques than STL. Those are inference models which allow the possibility of testing the statistical significance of the time components and accounting for different covariates. Change point models (Christensen and Rudemo, 1996) and Kalman filter (de Mol et al., 1999) are also examples of other methods utilised in the veterinary field to explore changes in time-series. These models are not designed to decompose time-series but are more focussed on optimising the detection of significant changes in the occurrence of an event of interest.

STL is presented here as an analytical tool for veterinary epidemiologists when tackling time-series explorations, being (i) a valid alternative to MA, (ii) a complementary method to GLM and GAM inference analyses, and (iii) a way to obtain temporal parameters that can be used to inform change-point and Kalman filter models. STL methodology produces robust outputs that provide a good fit to the data, maintains the transparency across the time-series decomposition (by examining the different diagnostic plots devised to work with this technique), and, what is perhaps its main strength, is ready and accessible for non-specialist analysts by utilising, for example, statistical packages that incorporate code to support the use of this methodology (e.g. STL function in R (R Development Core Team, 2009)). STL methodology was originally presented for count data but it has also been proved suitable to model binomial data in occurrence of disease as proportions (Bollag et al., 2005; Silawan et al., 2008), as has been presented in this paper.

Another typical objective when fitting models to time-series data is the prediction of future values. Jiang et al. (2010) compared STL with other widely-used methodologies to produce forecasting models with the presence of seasonal variation, seasonal autoregressive integrated moving average (SARIMA) and dynamic harmonic regression (DHR), concluding that the three methods are effective for time-series analysis.

4.3 Large scale monitoring schemes

This paper is an extended example of the analyses that are periodically performed on the BPHS data to explore the time components of the different lesions investigated through the scheme. BPHS abattoir records have been considered to provide reliable trends (Stark and Nevel, 2009) and this system of detailed post-mortem inspection is presumed to have good sensitivity and specificity. A similar inspection system, also focused on a limited number of organs and pigs, was found to have good classification characteristics (Enoe et al., 2003). The presence of operator bias affecting the gross pathology classification over time cannot be ruled out; this is unlikely to happen, however, as BPHS organises training and refresher days for the veterinarians and conducts internal comparisons on the same pigs assessed by different veterinarians, aiming to maintain assessor consistency over time. On the whole, any imperfection in the scoring in this investigation could be considered randomly distributed over time and it would have been reflected in our study as statistical noise allocated in the remainder. The difference in prevalence of EP-like lesions observed across the abattoirs is likely to represent genuine differences across farm (clusters/geographical areas) due to the uneven distribution of specific respiratory pathogens or the effect of health strategies implemented by the different pig groups and veterinary practices (Sanchez-Vazquez et al., 2010a). In a previous investigation (Sanchez-Vazquez et al., 2010b), it was observed that BPHS participating abattoirs appeared to capture the pig shipments from neighbourhood farms.

The BPHS offers a very large sample size – an average of 12,370 pigs per month were assessed – and in this scenario, statistical inference is secondary in favour of descriptive methods. The larger the sample size the closer the sample will be to the population and the more likely it is to find statistically significant results in the inference models. This situation is demonstrated in this paper, where the temporal features extracted by visual analytics are consistent with those from the inference model, after accounting for the effect of other potential confounding covariates. The study population was those pig herds assessed over time by BPHS. However, these findings could confidently be extrapolated to the English commercial pig finishing units (i.e. the reference population), as the BPHS assessments are likely to be highly representative of the monthly cross-sectional disease prevalence occurring in these pig units.

4.4 Conclusion

The evolution of EP-like lesions between July 2005 and June 2011 followed a "U" shape, with the initial reduction occurring during the first three years. The occurrence of this respiratory condition shows a seasonal pattern with the lowest level observed in July and peaks occurring in November and December. STL has a clear application in veterinary population medicine, particularly on national diseases monitoring, and it can be used in conjunction with inference models. This work shows an example of the utility of abattoir health schemes based on detailed post-mortem inspection as a large-scale health monitoring tool.

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Chapter VI

National monitoring of *Ascaris suum* related liver pathologies in English abattoirs: a time-series analysis, 2005-2010

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Abstract

Ascaris suum the most important internal parasite in farmed pigs world-wide. In England, the BPEX Pig Health Scheme (BPHS) monitors the prevalence of ascariosis in slaughtered finished pigs by identifying milk spots – the healing lesions caused by *Ascaris suum* larvae migration through the liver. This study investigates the trend of milk spot lesions from July 2005 to December 2010 to identify the progress made by the industry in controlling this parasitic disease. For visual explorations, the monthly prevalence for milk spots was modelled using "STL", a seasonal-trend decomposition method based on locally-weighted regression. Random effects binomial modelling accounting for clustering at batch level was used to test the significance of the trend and seasonality. Additionally, the differences in the milk spot prevalence trends for BPHS members (those that joined the scheme) and non-members were investigated and tested. A mean of 12,442 pigs was assessed per month (in 290 batches) across 12 pig abattoirs over the study period, from which a monthly mean of 7,102 pigs (159 batches) came from BPHS members. A mild overall decrease in prevalence of milk spots over the monitored period was identified as well as a seasonal variation which showed peaks in summer and at the beginning of autumn. BPHS members maintained a lower prevalence than non-members. The results from this work illustrate ascariosis as a persistent problem in current farm production.

1 Introduction

Ascariosis is considered the most important internal macro-parasitism present in farmed pigs worldwide (Stewart and Hoyt, 2006) and its control is advocated for several reasons including (1) farm economic losses attributed to depressed feed conversion efficiency (Stewart and Hale, 1988), (2) abattoir operator losses due to offal condemnations (Brown et al., 2007), (3) interference with post-vaccination immunity levels against *Mycoplasma hyopneumoniae* (Steenhard et al., 2009), and (4) a potential contribution to the persistence of *Salmonella* in the intestine – as suggested by the association between these bacteria and the hepatic lesions caused by the parasite (van der Wolf et al., 2001; Smith et al., 2011).

Milk spot liver, also known as white spots, refers to the whitish healing foci occurring in the liver stroma associated with the migrating *Ascaris suum* larvae (Stalker and Hayes, 2007). The presence of milk spots has been used to monitor herd prevalence of ascariosis and to investigate its epidemiology (Roneus, 1966; Bernardo et al., 1990; Goodall et al., 1991; Sanchez-Vazquez et al., 2010; Boes et al., 2010). Since 2005, the BPEX Pig Health Scheme (BPHS) has monitored the prevalence of milk spot liver in pigs slaughtered in the main pig abattoirs in England. On a regular basis, swine veterinarians carry out detailed post-mortem examinations in parallel to the routine official food-safety meat inspections. The scheme feeds back benchmarked results from abattoir inspections to the participating producers (i.e. those paying a fee to be part of the scheme) with the purpose of providing motivating strategies to reduce the parasite's prevalence. The inspections however, include all the batches submitted to the abattoir on the assessment days regardless of their BPHS membership status.

Understanding the temporal patterns of a disease is an essential step in learning about its epidemiology. *A. suum* development is prone to seasonal fluctuations subsequently influencing the within-year prevalence distribution of milk spots (Roneus, 1966; Stevenson, 1979; Wagner and Polley, 1999; Sanchez-Vazquez et al., 2010). Time-series analyses aim to provide a concise description of data correlated through time (Diggle, 1990), usually by exploring both time trend and seasonal pattern. Through a time-series analyses, Goodall (1991) explored the prevalence of *A. suum* infestations using abattoir liver condemnation data, but no recent investigations of the temporal distribution of this parasite prevalence has been published. In the current British industry, outdoor farming and bedded flooring are common, both potential determinants for the presence of *A. suum* (Roepstorff and Nansen, 1994; Dangolla et al., 1996; Sanchez-Vazquez et al., 2010); whilst on the other hand, efficient antihelminthic protocols are expected to be in use. In this respect BPHS, with over five years of consistent monitoring in English abattoirs, offers a unique opportunity to explore the temporal patterns of the prevalence of milk spots as a proxy to reflect the underlying prevalence of *A. suum*.

This paper presents a time-series analysis to explore the prevalence of milk spot livers, as reported by BPHS from July 2005 to December 2010. This work's main objective is to provide an up to date seasonal pattern on the prevalence of milk spots and to identify the progress made by the industry in controlling this parasitic disease, particularly by comparing members versus non-members. Furthermore, the intention of this study is to reflect the relevance of ascariosis in the English system by reporting the prevalence of its lesion, which might trigger the development/review of new control strategies of this parasite.

2 Material and methods

2.1 Data source and study population

BPHS has monitored the prevalence of milk spot livers across the largest pig abattoirs in England since July 2005. Pig veterinarians trained in this method of assessment at the abattoir inspection line assess every second pig in a batch (up to fifty pigs assessed) for gross pathology. BPHS organises training and refresher days for the veterinarians and conducts internal comparisons on the same pigs assessed by different veterinarians, aiming to maintain assessor consistency over time. This study used the combined BPHS records, for both members and non-members, available from the 12 abattoirs that participated in BPHS from July 2005 to December 2010.

The abattoirs are geographically widely distributed across England (see Figure 1). A total of 821,159 pigs (19,160 batches) submitted from 1,517 herds were assessed over the period studied.

Figure 1. Map of Great Britain showing England shaded and representing with dots the location of the 12 abattoirs included in the study.

2.2 Time-series modelling

2.2.1 The strategy

The time-series analyses were carried out in two steps. Firstly, visual analytics were used to graphically investigate and describe the trend and the seasonal pattern. Secondly, the trend, the effects of season (month) and BPHS membership were statistically tested.

2.2.2 Time series visual explorations

For exploratory purposes, time-series "fractions" were composed of monthly prevalence estimates, computed as the number of pigs affected with milk spots, divided by the number of pigs assessed. The seasonal cycle was studied yearly (12 month). This exploratory process was carried out using a nonparametric procedure for seasonal-trend decomposition of time-series based on locally-weighted regression (loess), known as "STL" (Cleveland et al., 1990). This method is a filtering procedure for decomposing a time-series into additive components of variation (trend, seasonal and the remainder) by the application of loess smoothing models (Cleveland et al., 1990). STL has good visualization capabilities which make it a useful tool for visual analytics (Hafen et al., 2009). The adequacy of the model fit was assessed by graphical diagnostic methods (Cleveland et al., 1990). Using STL, the overall trend of both members' and non-members' combined data and the seasonal pattern was explored. Additionally, the STL trend for the members and non-members was explored separately.

2.2.3 Statistical testing

Batch prevalence was modelled against time in monthly intervals. The seasonal effect of the month (i.e. January, February, and so on) and the effect of membership status (member versus non-member) were tested by being added as model covariates. Four models were attempted in these analyses: (1) a simple binomial model, (2) a binomial model with random effects to allow for clustering at batch level, (3) a zero-inflated binomial model, and (4) a beta-binomial model allowing for clustering at batch level. These two latter models were explored due to the high relative number of batches with zero prevalence of milk spots. The measure of the goodness of fit Akaike's Information Criterion (AIC) was used for comparison among the different model distributions and also to compare nested models through a stepwise covariates selection process. Wald test was used to examine the significance level (p value <0.05) of the variables retained in the final model, particularly for that with multiple classes (i.e. month). All analyses and graphs were performed using the R statistical software environment (R Development Core Team, 2009) using libraries stats, epicalc, lme4 and VGAM.

3 Results

The mean number of pigs assessed per month was 12,442 pigs (standard deviation (SD) 2,527), with a mean of 290 batches (SD 60). Of those, the mean number of pigs from BPHS members was 7,102 pigs (SD 1,691) with a mean of 159 batches (SD 39). A total of 34,168 pigs (from 5,370 batches) were affected with milk spots livers which represent 4.2% of the total pigs inspected (3.7% of the members and 4.8% of non-members).

3.1 Results from the exploratory analyses

The STL trend identified (Figure 2, graph (a)) an initial decline in the prevalence of milk spot liver, particularly between 2006 and 2008. There is change in the trend, however, with the prevalence of the lesions increasing slightly over 2010. The STL seasonal component observed (Figure 2, graph (b)) shows an increase of milk spot lesions at the end of the summer and beginning of autumn, and a decline in winter and spring. Scheme members and non-members follow two distinctive trends (Figure 2, graphs (c) and (d) respectively). It is observed that the trend for the members levels out following an initial bump, and thereafter maintains a prevalence of under 4% from mid 2007; while the non-members, with higher initial prevalence than the members, had a marked decrease until 2009 at which time the prevalence started to increase.

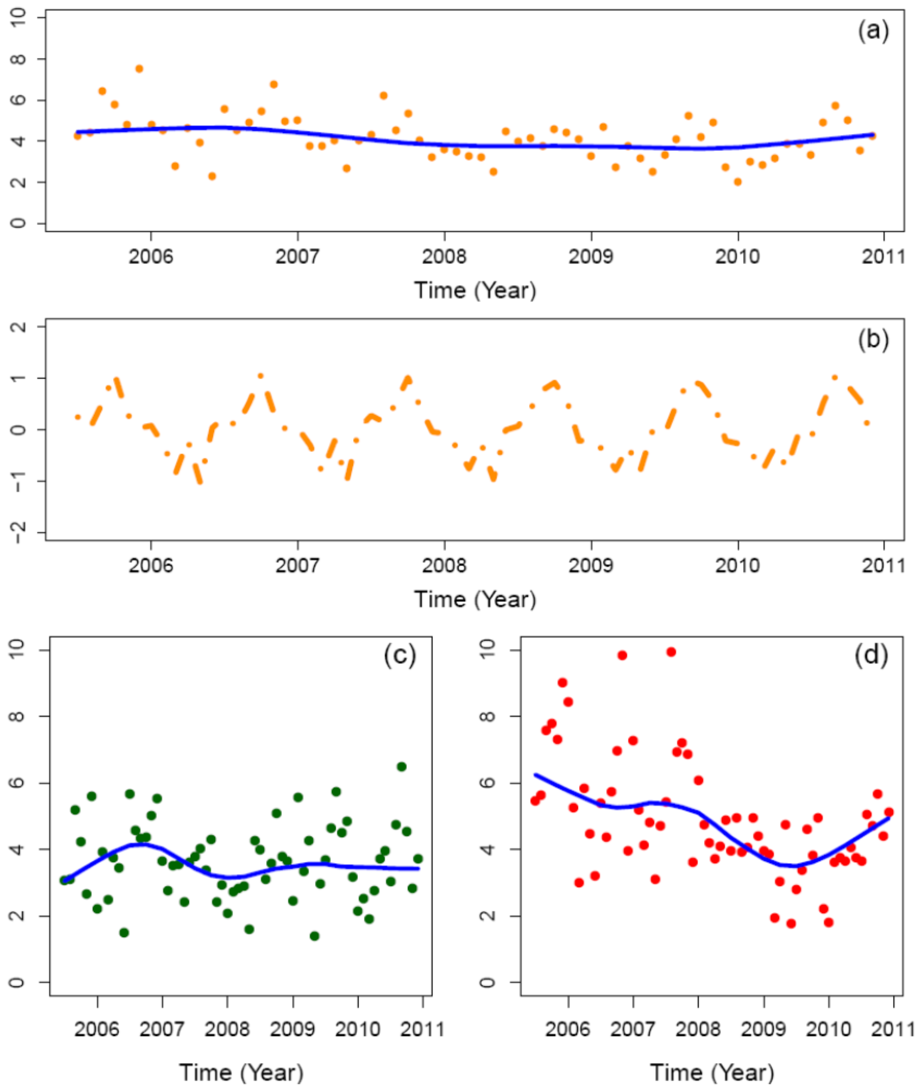

Figure 2. Trend and seasonality of the prevalence of pigs affected with milk spots in 12 English abattoirs (2005-2010), STL method. In the graph (a) the dots represent the monthly prevalence for all BPHS assessments (combining results for members and non-members) and the line is the STL fitted trend. The graph (b) presents the STL seasonal pattern per 12 months for all BPHS members. In graph (c) the dots represent the monthly prevalence for BPHS members and the line their STL fitted trend. In graph (d) the dots represent the monthly prevalence for BPHS non-members and the line their STL fitted trend. The units in the vertical axis represent the percentages of pigs affected with milk spot livers.

3.2 Results from the statistical testing

The random effects binomial model allowing for clustering at batch level provided the best goodness of fit, AIC 33,750. The AIC values for the simple binomial, the zero-inflated binomial and the beta-binomial models were 163,567, 97,621 and 50,398 respectively. The results for the final multivariable random effects binomial model are presented in Table 1. Overall, there is a significant trend toward reduction (estimated coefficient -0.026, p-value <0.001). September and October were the two months which had the highest (significant) prevalence compared with March, the month with the lowest prevalence (and taken as the baseline). There are significant differences between members and non-members, with non-members having a higher prevalence of milk spots over the period studied.

Table 1. Estimated coefficients for the covariates in the multivariable random effects binomial model for the prevalence of milk spot livers in finishing pigs slaughtered in English abattoirs, 2005-2010. N=19,160 batches.

Farm variable	Level	Estimate	Standard error	P-value
Trend	Monthly	-0.026	0.002	<0.001
Month	July	-0.132	0.151	0.383
	August	0.019	0.153	0.902
	September	0.528	0.149	<0.001
	October	0.751	0.144	<0.001
	November	0.151	0.149	0.313
	December	-0.052	0.165	0.75
	January	0.31	0.154	0.045
	February	0.302	0.157	0.055
	March	0	-	-
	April	0.128	0.154	0.29
	May	0.026	0.158	0.577
	June	0.063	0.163	0.804
Being a BPHS member	Non-member	0.425	0.059	<0.001
	Member	0	-	-

4 Discussion

This paper investigates and presents the prevalence of milk spot liver in English pigs from July 2005 to December 2010 with focus on time trend and seasonality, in an attempt to reflect the temporal pattern of *A. suum*. This is facilitated by the exceptionally large sample size of quality abattoir inspection data sourced from the BPEX Pig Health Scheme.

The overall trend shows a general reduction over the monitoring period (2005-2010). This trend is, however, composed of both members' and non-members' results which behave as two different populations with significant differences being found between them. The members had, since the beginning of the BPHS monitoring, a lower prevalence (compared to non-members) which was maintained across the monitoring period. Despite the members and their vets receiving feed-back from the abattoir results, only a mild appreciable reduction in prevalence (after an initial worsening) was evident. Perhaps this level reflects an "as good as it gets" position on the control of this parasite with current strategies in the English production system. In a previous time series-analyses carried out in Northern Ireland (Goodall et al., 1991) where slatted floor systems are widely used, an increasing trend was found, reporting a 9% prevalence of pigs affected with liver lesions in 1989 (the end of the study period), much higher than the level observed in this study.

The prevalence of milk spot livers in pigs submitted by non-members decreased considerably between 2005 and 2009. Although the BPHS non-members did not receive feed-back on the prevalence of milk spots liver in their herds, vet practices might recommend similar worming and control protocols to all their clients. The information from BPHS members could have been used indirectly in this way, to influence non-members' control strategies. Additionally, some of the larger integrated pig businesses only have a few units registered as BPHS members but they implement a worming strategy which they roll out across all finishing units. Overall, the difference in prevalence observed between members and non-members might reflect different attitudes in the control of parasitic diseases – thus, those producers not willing to join the health scheme might also be less prone to implement efficient worming control strategies.

The STL results show the prevalence of milk spot livers increasing at the end of summer/ beginning of autumn and declining in winter/spring. This pattern is similar to that previously reported (Goodall et al., 1991) and is explained by the development of *A. suum* eggs associated with warmer temperatures (Wagner and Polley, 1999). Such a clear seasonal pattern serves to illustrate (overall) insufficient control of the parasite.

BPHS abattoir records have been considered to provide reliable trends (Stark and Nevel, 2009) and this system of detailed post-mortem inspection is presumed to have good sensitivity and specificity. A similar inspection system, which also focused on a limited number of organs and pigs, was found to have good classification characteristics (Enoe et al., 2003). The presence of operator bias affecting the gross pathology classification over time cannot be ruled out; this is unlikely to happen, however, as the lesion definition has not changed since BPHS started. On the whole, any imperfection in the scoring in this investigation could be considered randomly distributed over time. The study population was defined as those pigs assessed over time by BPHS. We could, however, confidently extrapolate our findings to the English commercial (professional) pig finishing units, as the BPHS assessments are likely to be highly representative of the monthly cross-sectional disease prevalence occurring in these pig units.

4.1 Conclusion

This study detects a mild reduction in the prevalence of milk spots in English farmed finishing pigs over a monitoring period from 2005 to 2010. Producer members of BPHS have maintained lower prevalence levels of milk spots than non-members. This study shows that ascariosis is a persistent problem in English farmed pigs and provides an example of the utility of abattoir health schemes based on detailed post-mortem inspection as a large-scale health monitoring tool.

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Chapter VII

Identifying associations between pig pathologies using a multi-dimensional machine learning methodology

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Abstract

Abattoir detected pathologies are of crucial importance to both pig production and food safety. Usually, more than one pathology coexist in a pig herd although it often remains unknown how these different pathologies interrelate to each other. Identification of the associations between different pathologies may facilitate an improved understanding of their underlying biological linkage, and support the veterinarians in encouraging control strategies aimed at reducing the prevalence of not just one, but two or more conditions simultaneously. Multi-dimensional machine learning methodology was used to identify associations between ten typical pathologies in 6485 batches of slaughtered finishing pigs, assisting the comprehension of their biological association. Pathologies potentially associated with septicaemia (e.g. pericarditis, peritonitis) appear interrelated, suggesting on-going bacterial challenges by pathogens such as *Haemophilus parasuis* and *Streptococcus suis*. Furthermore, hepatic scarring appears interrelated with both milk spot livers (Ascaris suum) and bacteria-related pathologies, suggesting a potential multi-pathogen nature for this pathology. The application of novel multi-dimensional machine learning methodology provided new insights into how typical pig pathologies are potentially interrelated at batch level. The methodology presented is a powerful exploratory tool to generate hypotheses, applicable to a wide range of studies in veterinary research.

1 Background

Abattoir post-mortem inspection offers good opportunities for pig health monitoring (Elbers et al., 1992) and it has been widely used as a data source for epidemiology-based analyses. Most of these studies focus on the identification of risk factors influencing the presence of the major abattoir pathologies: pneumonia, pleurisy and milk spot liver (Cleveland-Nielsen et al., 2002; Enoe et al., 2002; Fraile et al., 2010; Hurnik et al., 1994; Meyns et al., 2011; Ostanello et al., 2007; Sanchez-Vazquez et al., 2010a; Sanchez-Vazquez et al., 2010b). Few reports investigate how the different pathologies are interrelated (Elbers et al., 1992; Huey, 1996; Kritas and Morrison, 2007). Identification of the associations between pathologies may assist in elucidating theories on their biological connection and could greatly contribute to facilitating their control – for example by encouraging veterinarians to establish intervention strategies aimed at reducing the prevalence of not just one, but two or more conditions simultaneously. Knowledge of associations between lesions could also be employed to inform official abattoir inspection systems, in which the presence of one pathology could trigger an inspection for others.

Official routine meat inspections are implemented world-wide with the main objective of ensuring food safety. This system, however, is imperfect and is particularly lacking in sensitivity (Bonde et al., 2010; Enoe et al., 2003). Pig health schemes were proposed to provide an integrated system to capture abattoir information based on more detailed post-mortem inspection (Willeberg et al., 1984) which is considered to improve classification characteristics, particularly sensitivity (Enoe et al., 2003). Good examples of these initiatives in Europe are the British pig health schemes. On a regular basis, swine specialists carry out detailed post-mortem examinations in parallel to the official food-safety routine meat inspections. These schemes monitor the presence of various pathologies detected by means of a detailed inspection of the pluck and the skin of the slaughtered pig. These pathologies are normally associated with a reduction in performance traits or are potential indicators of the presence of welfare problems in the herds (Huey, 1996; Sorensen et al., 2006; Stewart and Hale, 1988; Taylor et al., 2010).

Graphical modelling has been increasingly used in veterinary epidemiology to investigate and express the relationships between factors influencing diseased/unproductive status in livestock (Jensen et al., 2009; Lewis et al., 2011; Otto and Kristensen, 2004; Pedersen et al., 2006; Rougoor et al., 1999; Steeneveld et al., 2009). Frequently, studies utilising graphical models are based on structure discovery approaches, which are data-driven multivariate methodologies resulting in graphical outputs such as networks or path/chain models. Structure discovery has been employed to explore how mastitis and fertility management influence production in dairy herds (Rougoor et al., 1999); to identify changes in pig behaviour related to early piglets mortality (Pedersen et al., 2006); to investigate the most likely pathogens involved in clinical mastitis in dairy cows (Steeneveld et al., 2009); and to identify those farm risk factors associated with bovine viral diarrhoea (Lewis et al., 2011). Besides these examples, other studies employed graphical models informed using existing/expert knowledge to describe risk factors influencing the prevalence of *Mycoplasma hyopneumoniae* (Otto and Kristensen, 2004); and to estimate the risk of leg disorders in finishing pigs (Jensen et al., 2009). A crucial distinction among the abovementioned papers, is that these two latter studies (Jensen et al., 2009; Otto and Kristensen, 2004) did not use structure discovery to inform structure of the network, but were rather based on published knowledge and expert opinion. The latter is highly subjective and if, as in this study, extensive data are available, then extracting the co-dependence network structure from observed data provides objective and robust empirical analyses.

Multi-dimensional machine learning methodology (also known as Bayesian graphical modelling) is a variety of graphical modelling structure discovery techniques used to identify the dependency structure that encodes the joint probability distribution between variables (Friedman and Koller, 2003; Heckerman et al., 1995), allowing for both visualization and estimation of associations. In short, this process consists of a series of model searches to identify the multi-dimensional model that best explains the data, using Bayes factors to compare between models (Lewis et al., 2011). This approach allows estimation of the associations between variables and distinguishes between direct and indirect dependence (Friedman and Koller, 2003) (dependence being equivalent to biological association), contributing to generate hypotheses about the nature of the interrelationships. Multi-dimensional machine learning methodology offers an intuitively appealing and technically elegant way to investigate multiple associations between variables compared to more conventional multivariate statistical approaches (e.g. principal component and factor analyses). This methodology is used extensively in fields such as bioinformatics and genetics (Needham et al., 2007; Poon et al., 2007a; Poon et al., 2007b) and only recently has been applied in the veterinary field (Lewis et al., 2011).

This paper uses a multi-dimensional machine learning methodology to identify whether associations exist between the different pathologies reported by the British pig health schemes. The results of this study could assist veterinarians in the control of these conditions by implementing strategies to control several conditions at once. These results could be also utilised to review current pig abattoir inspection strategies, and inform more targeted risk based inspections. Farmed pigs are normally considered as a grouped unit, where complex interactions take place between the environment, mainly determined by the housing system and the husbandry practices, and the pigs, characterised by their genetics, idiosyncratic behaviour and baseline health status (Gonyou et al., 2006). For these reasons this study focuses on the interrelationship occurring between pathologies at batch level.

2 Methods

2.1 Data source

Abattoir data were accessed through the databases of the two pig abattoir lesion scoring health schemes which exist in Great Britain: Wholesome Pigs Scotland (WPS) (covering Scotland) and British Pig Health Scheme (BPHS) (covering England and Wales) (Sanchez-Vazquez et al., 2010a). The health schemes provide services in 17 pig abattoirs. Both schemes obtain a sample from each batch of pigs by assessing every second pig on the slaughter line. The scoring was carried out by swine veterinarians trained in this method of testing on the abattoir inspection line. The data were from a three year period (July 2005 to June 2008).

2.2 Dataset

For the purpose of this investigation, a batch is defined as a group of pigs from a single farm submitted to the abattoir on a particular date. A total of 6485 batches were included, submitted from 1138 farms, with a median of 4 batches assessed per farm (first quartile 2, third quartile 8). All the batches consisted of exactly 50 pigs assessed.

2.3 Scoring for the different pathologies

Ten pathologies reported by the health schemes are included in this study: Enzootic-pneumonia-like lesions, pleurisy (pleuritic lesions), milk spots, hepatic scarring, pericarditis, peritonitis, (lung) abscess, pyaemia (pyaemic lung lesions), tail damage and papular dermatitis. A further explanation on the gross pathology description, the most typical cause associated and the scoring system for each condition are presented in Table 1. In this study, a positive case for each pathology was defined as a pig affected with any degree of lesion and a negative when lesions were absent.

Table 1. Summary of the gross pathology description of conditions studied with their most typical cause and the scoring system.

Pathology	Gross pathology and most typical cause	Scoring system
Enzootic pneumonia-like lesions	A red-tan-grey discoloration, collapse, and rubbery firmness affecting cranioventral regions of the lungs in a lobular pattern. *Mycoplasma hyopneumoniae* is the causal infectious agent (Caswell and Williams, 2007).	Represent the approximate percentage of lung with consolidation. Scale from 0 to 55 in 5 steps.
Pleurisy	Fibrous/fibrinous pleural adhesions. Can be associated with *Actinobacilus pleuropneumoniae*, *Pasteurella* spp, *Mycoplasma hyorhinis*, *Mycoplasma hyopneumoniae,* swine influenza and *Haemophilus parasuis.* (Enoe et al., 2002)	Three categories represent severity of the lesion with baseline absence.
	Focal areas of bronchopneumonia with overlying pleurisy often associated with *A. pleuropneumoniae* usually affecting the middle or caudal lung lobes (Caswell and Williams, 2007).	Binary, present or absent.
Milk Spots	Whitish foci, occurring in the liver stroma when *Ascaris suum* larvae are immobilised by the host's inflammatory reaction (Stalker and Hayes, 2007).	Binary, present or absent.
Hepatic scarring	Mild fibrotic lesions affecting the capsule of Glisson, with no liver parenchyma alteration. Possibly associated with healed *Ascaris suum* lesions.	Binary, present or absent.
Pericarditis	Inflammation of the pericardium, usually fibrinous. Unspecific condition that could be associated with bacterial diseases, e.g. Glasser's disease and pasteurellosis (Grant Maxie and Robinson, 2007).	Binary, present or absent.
Peritonitis	Fibrous/fibrinopurulent lesions typically associated with *Arcanobacterium pyogenes* and *Escherichia coli.* Serofibrinous lesions associated with *Haemophilus parasuis* (Glasser's disease) and *Streptococcus suis* (Brown et al., 2007; Reams et al., 1994).	Binary, present or absent.
Abscess	Localised/encapsulated collection of pus within the lung. Various pathogens involved, typically *Arcanobacterium pyogenes* (Huey, 1996).	Binary, present or absent.
Pyaemia	Multiple small abscesses in the lung parenchyma. Pyaemic spread of infection from other focus: *Arcanobacterium pyogenes* frequent involved (Huey, 1996).	Binary, present or absent.
Tail damage	Presence of old or recent tail lesions. Typically associated with tail biting (Taylor et al., 2010).	Binary, present or absent.
Papular dermatitis	Reddish papules/nodules found on belly, head and buttocks or widespread across the skin, depending on the severity. This lesion is potentially associated with Sarcoptic mange (Cargill et al., 1997).	Three categories: accounting for severity and distribution of the skin lesions.

2.4 Consistency in the scoring of the pathologies

Both health schemes carried out exercises to standardise the definition of each lesion across the inspectors. One WPS assessor was involved in the training of all the other inspectors that carried out WPS and BPHS assessments during the three year period included in this study. Once a year, all the inspectors underwent a refresher/training day where the same pigs and pathologies were assessed by all the assessors and feed-back was provided by the trainer. These assessment exercises aimed to maintain the consistency in the scoring criteria across assessors by identifying and correcting potential misclassifications. Furthermore, the schemes aimed to include at least two assessors per abattoir and to place each assessor in at least two different abattoirs, thereby minimising the potential of operator bias.

2.5 Definition of pathology batch-status variables

The machine learning approach utilised requires working with categorical variables. Batches were categorised into lesion present/absent using the frequency distribution of the batch prevalence for the different pathologies to determine data-derived cut-off points (further details are provided in supplementary material Figure 1 and Figure 2). In the context of this study, where all the batches have the same number of pigs inspected (i.e. 50), frequency and proportion are equivalent and the cut–offs are defined in terms of frequencies per batch. For enzootic pneumonia-like lesions, three categories were identified based on within batch prevalence: EP high) when more than 25 pigs were affected with any degree of severity; EP moderate-low) when between one and 25 pigs were affected; and EP zero) when no pigs were affected. For pleurisy, three categories were also identified based on within batch prevalence: PL high) when more than seven pigs were affected; PL moderate-low) when between one and seven pigs were affected and PL zero) when no pigs were affected. The three prevalence level categories identified for enzootic pneumonia-like lesions and pleurisy were each separated into three binary variables (e.g. EP high [yes, no], and so on) to reflect the pathology batch-status. Splitting the prevalence level categories into three binary variables was chosen over creating a single multinomial variable to add flexibility in the modelling and facilitate the interpretation of the model outputs. For the other pathologies which have a much lower prevalence (i.e. milk spots, hepatic scarring, pericarditis, peritonitis, papular dermatitis, tail damage, abscess and pyaemia) batches were considered positive if at least one pig was found affected, and negative otherwise. In summary, the ten different pathologies were studied through 14 binary variables reflecting the pathology batch-status. A data break-down of the frequencies for the pathology batch-status variables is presented by pairs in Table 2.

Table 2. The break-down of the frequencies of the variables expressing batch-status for the different pathologies studies by pairs, N=6485 batches of slaughtered pigs.

		EP			PL			MS	HS	PC	PT	Abs.	Pya.	Tail
		High	M/L	zero	high	M/L	zero							
	high	656	1124	46	-	-	-	-	-	-	-	-	-	-
PL	M/L	614	2679	437	-	-	-	-	-	-	-	-	-	-
	zero	80	642	207	-	-	-	-	-	-	-	-	-	-
MS		417	1327	196	508	1163	270	-	-	-	-	-	-	-
HS		842	2544	336	1038	2158	526	1328	-	-	-	-	-	-
PC		986	2970	305	1531	2393	337	1279	2550	-	-	-	-	-
PT		259	694	82	419	541	75	357	808	860	-	-	-	-
Abscess		326	851	55	564	598	70	387	732	882	228	-	-	-
Pyaemia		154	362	26	243	267	32	174	383	388	172	171	-	-
Tail		109	353	75	180	316	41	137	275	362	136	115	126	-
PD		344	1008	106	471	774	213	516	959	1009	269	319	136	144

Abbreviations/initials: EP, enzootic pneumonia-like lesions; PL, pleurisy; MS, milk spots; HS, hepatic scarring, PC, pericarditis; PT, peritonitis; Abs., abscess; Pya., pyaemia; Tail, tail damage; PD, papular dermatitis; M/L, moderate/low.

2.6 Multi-dimensional machine learning methodology

The process explained below aims to identify an optimal multi-dimensional model, i.e. a graphical model displayed as a network of connections, where each connection (arc) describes a statistically significant association between the different lesions in the data. Figure 1 schematically represents the machine leaning structure discovery process utilised, which is initiated with numerous series of searches followed by steps to summarise the results of each search. This methodology consists of fitting models which are network structures technically referred to as directed acyclic graphs (a graph with no loops), in which nodes correspond to the pathology batch-status variables and arcs between nodes (represented by arrows) indicate that a direct probabilistic dependency (e.g. an association) exist between nodes.

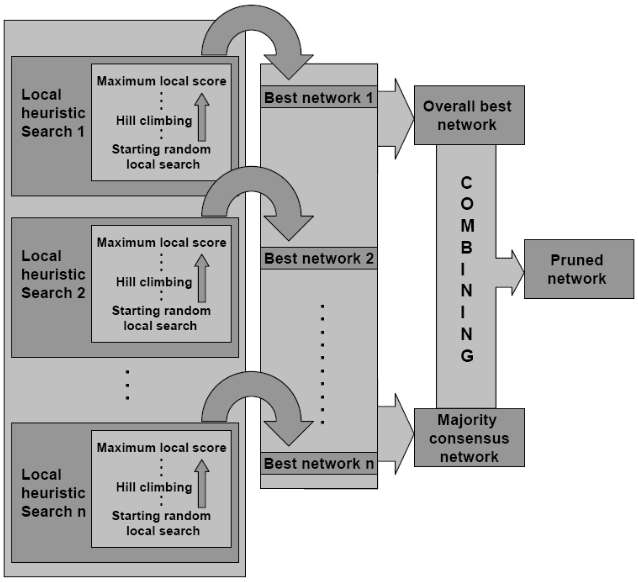

Figure 1. Diagram representing the machine learning structure discovery steps. The process starts with local searches, where local best networks are recruited, then the overall best network and the majority consensus network are identified. Finally the combination of the two latter structures leads to the pruned network.

2.7 Direction of the arrows

The direction of the arcs connecting nodes is informed by the data, reflecting the dependency structure which generated the data (Needham et al., 2007). The direction only implies association and says nothing of causality. Arc direction is as a result of the underlying mathematics used to construct the models (technically the graph denotes a factorisation of the joint probability distribution of the data). Models with particular arc directions may be better fit to the data than with the reversed directions, and therefore preferred, however, it would be incorrect with this information alone to infer that the biological dependence between two nodes is supported more in one direction over another, all that can be inferred is that association exists between nodes.

2.8 Searching for locally optimal structures

The machine learning structure discovery process was performed through series of local heuristic searches using a standard approach proposed by Heckerman et al. (Heckerman et al., 1995). Locally optimal models are identified by random-restart local hill climbing searches, also known as a "greedy search" (Needham et al., 2007), which seek to maximise the goodness of fit metric (network score) for each model. This network score is given by the (log) marginal likelihood of the data given the model; equivalent to the Bayes factor when using equal prior on each model structure. This search process can be thought of as roughly analogous to stepwise regression in linear modelling but conducted in multiple dimensions where the initial model from which the search commences is randomly chosen. The interrelationships within different batch-status categories for the same pathology are inversely related – i.e. when one batch-status is present the others are not. Therefore arcs connecting the different batch-status categories for the same pathology (e.g. EP zero with EP high, or EP high with EP mild/moderate, and so on) were banned from the search.

2.9 Summarising the results from the local searches

Alternative and competing explanations of the data are produced during the local search process; different local searches may lead to different structural features (e.g. arcs) that appear in some networks but not in others (Friedman and Koller, 2003). A great deal of commonality across the search results is expected and strong features should be extracted reliably (Friedman and Koller, 2003). The aim is to produce an optimal structure that robustly represents the main associations. Three main ways are proposed to summarise the results from the local searches:

1. The "overall best network" is the single structure with the best score (according to the Bayes factor) across all the searches. This structure identifies the potential pathways (composed of sets of arcs) of associations between variables. Some of these pathways may be weak, however, i.e. only identified for this particular network and may incur over-fitting; a common problem within structure discovery approaches (Needham et al., 2007).
2. The "majority consensus network" is the structure that represents those common features present in the majority of the best-scored networks identified across all the heuristic searches. By using this, those associations (arcs) that were present in the majority (over 50%) of all the locally best networks were kept. This approach is typically employed in phylogenetic studies (Huelsenbeck and Ronquist, 2001) and it has been suggested for structure discovery (Lewis et al., 2011).
3. The "pruned network" is the structure that combines the two approaches mentioned above to produce a more robust output. Only those arcs that were part of the overall best network and also recruited by the majority consensus network were kept. Lewis et al. (Lewis et al., 2011) proposed this approach mimicking pruning performed in decision tree inferences, which is essential to reduce over-fitting (Helmbold and Schapire, 1997).

2.10 Identifying the final network

Out of the three structures described above, the pruned network is the model that provides the most robust and conservative approach and is therefore considered in this paper as the principal result. The strength of the association between two nodes (pathology batch-status variables) present in the pruned network was estimated by calculating the relative risk (RR) (also known as risk ratio) (Dohoo et al., 2003). RR is calculated as the proportion of batches affected with condition A given condition B is present in the batch, divided by proportion of batches with the condition A but with condition B not present. The 95% confidence intervals (CI) for the RR were estimated using Monte-Carlo simulation.

2.11 Parameters in the search algorithm

Three major characteristics define the algorithm of the heuristic search:

- set.seed – a single value that sets the starting point for the search.
- i.permutations – a number that defines the times an initial empty network is perturbed to construct a random network from which a stepwise search is performed.
- max.parents – a number between 2 and total number of variables minus 1. This number defines the maximum number of arcs reaching a particular node. In this study no restrictions were placed upon the number of parents and the maximum, 13, was allowed in all searches.

The optimal number of local searches required to identify a robust machine learning structure is problem specific. In this study, the number was determined empirically by running two parallel sets of searches, differing in the set.seed value. The number of local searches was increased until both sets reached the same majority consensus network, thereby suggesting that a sufficient numbers of searches had been run to provide robust outputs. The results from both sets of searches were pooled to identify the best overall single network which, combined with the majority consensus network, led to the pruned network.

The analyses were performed in R (R Development Core Team, 2009) using a library written by FIL (freely available upon request) to perform the structure search. Other broadly similar libraries are available for use within R from CRAN (Comprehensive R Archive Network) website, and similar toolboxes are available for use with MATLAB.

3 Results

Empirical investigation determined that 10000 local searches were sufficient to ensure robust modelling results.

3.1 Graphical outputs

The "majority consensus network" is presented in Figure 2 and provides complementary information to the main output from this investigation, the "pruned network", which is presented in Figure 3 completed with estimated RRs. The arcs presented in the "pruned network" could be identified in the "majority consensus network" to determine the percentage of local searches in which the particular arc appears, informing about the robustness. Thus, the "majority consensus network" (Figure 2) shows that the connections leading to milk spots from hepatic scarring and papular dermatitis, are the most robust – present in more than 90% of searches. In the pruned network (Figure 3) these arcs are retained, and it is observed that those batches with hepatic scarring had a moderate risk of milk spots compare to those batches not presenting hepatic scaring; likewise batches with papular dermatitis had a milder risk of milk spots compare to those with papular dermatitis absent. Figure 3 also shows that batches with mild or moderate levels of pleurisy were more likely to be enzootic pneumonia-like free than those with other category levels of pleurisy. The pneumonia free batches were more likely to be also free of papular dermatitis than those with pneumonia. Batches with a high level of enzootic pneumonia-like lesions had a moderate risk (i.e. RRs between 1.5 and 2.5) of having a high level of pleurisy compare to those batches with pneumonia absent or with moderate/low level. Having abscesses is associated with batches with a higher level of pleurisy compare to those with no abscesses. Batches with a moderate/low level of pleurisy had a negative risk of abscess and pericarditis compare to other batches with other levels of pleurisy. There is stronger risk (i.e. RRs over 2.5) of having peritonitis if pericarditis is present in the batch than if it is absent; conversely those batches with zero level of pleurisy are more likely to be peritonitis free than those with pleurisy present. Batches with peritonitis also had a milder risk (i.e. RRs between 1 and 1.5) of hepatic scarring compare to batches without peritonitis. Batches with pyaemia had a mild risk of hepatic scarring and a strong risk of having tail damage compare to those batches with pyaemia absent.

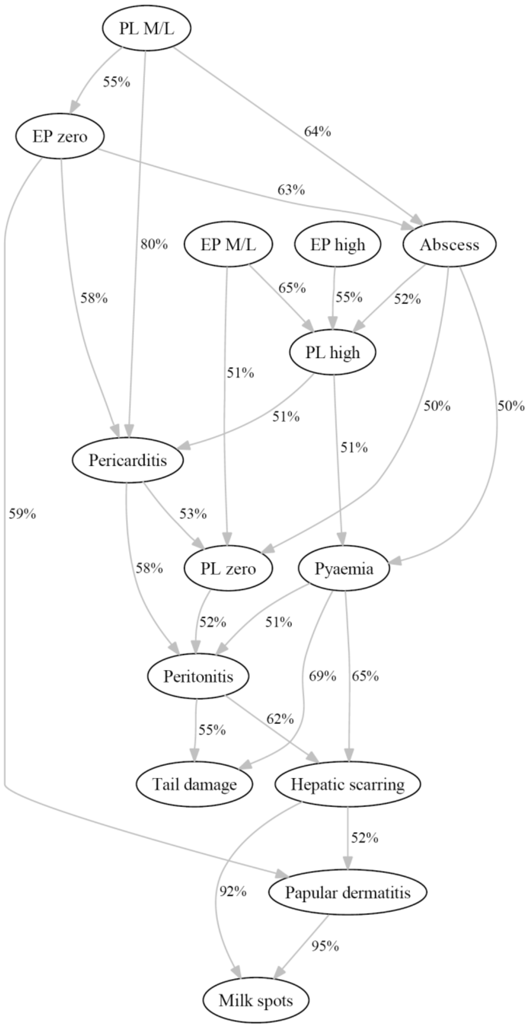

Figure 2. Associations between the variables expressing the batch-status for the different pathologies as identified by the majority consensus network, N= 6485 batches of slaughtered pigs. This network encloses the joint probability of the pathology batch-status variables with the arrows representing the associations between them (pointing in the direction reflected by the data structure). The figures beside the arrows represent the percentages of local searches in which the arc appears.

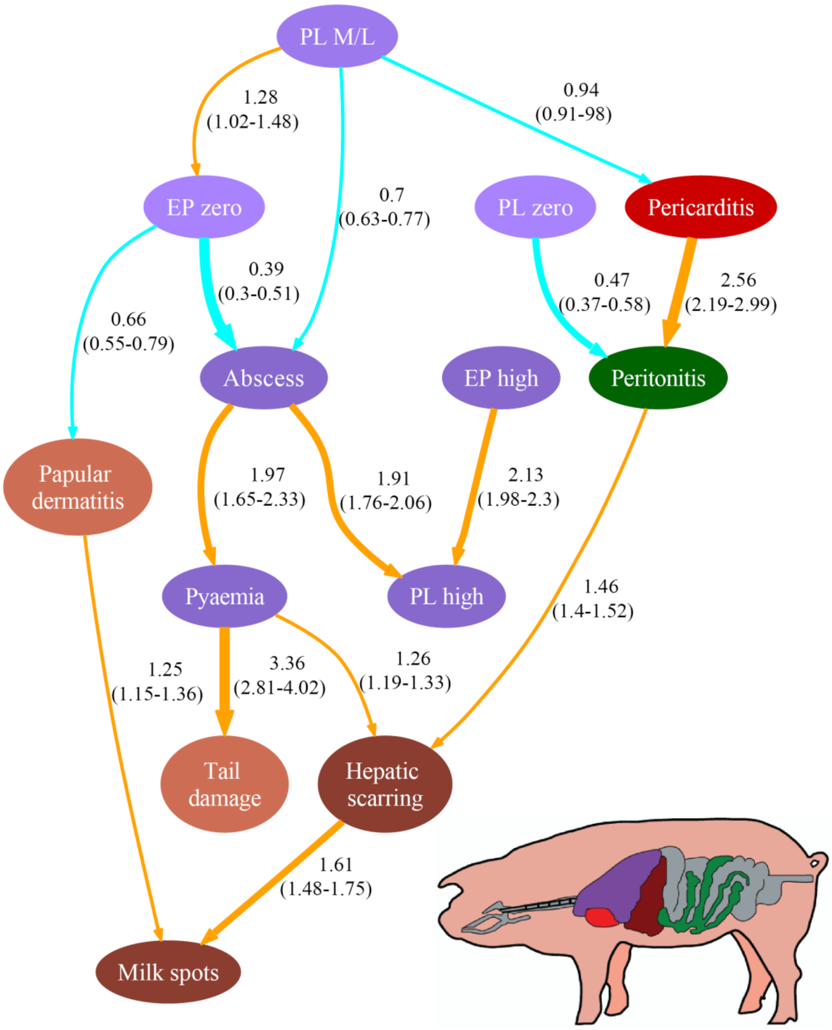

Figure 3. Associations between the variables expressing the batch-status for the different pathologies as identified by the pruned network, N= 6485 batches of slaughtered pigs. This network encloses the joint probability of the pathology batch-status variables with the arrows representing the associations between them (pointing in the direction reflected by the data structure). The figures beside the arrows represent the estimated relative risk (RR) reflecting the strength of the association (the figures between brackets represent the 95% confidence intervals). The thickness of the arrows reflects the strength of the association. The thinnest arrows represent mild associations (RRs between 0.66-1 and 1-1.5); the intermediate thickness represents moderate associations (RRs between 0.5-0.66 and 1.5-2.5); and the thickest ones represent strong associations (RRs less than 0.5 and over 2.5). The arrows in orange represent positive association (RRs>1) and the arrows in blue represent negative associations (RRs<1). To facilitate the visualization the variables are colour-coded according to the organs they are attributed to: purple for lungs, red for the heart, brown for the liver, green for the peritoneum, and pink for the skin/tail. Colour gradients are used for enzootic pneumonia and pleurisy batch-status variables to indicate the different levels of prevalence (high, moderate/low and zero).

4 Discussion

This paper describes the application of a multi-dimensional machine learning methodology to multivariate epidemiological analyses. Applying this methodology to the data comprising of the typical pathologies present in slaughtered finishing pigs has led to an easy to interpret, highly visual, and statistically robust output: a network in which the main associations between the pathologies are easily identifiable.

4.1 The interrelationship between the pathologies

This study has provided information on the nature of hepatic scarring which is thought to be a post healing stage of milk spots; but for which other aetiologies cannot be discarded. The results suggest that both *Ascaris suum* and systemic bacterial infections are independently interrelated with the presence of the liver capsule scarring. The former is reflected in the moderate association with milk spots, which seems to be a highly robust interrelationship as it was recruited in 92% of the searches. Different stages of *A. suum* parasitism within the same batch may take place; leading to coexistence of active milk spot lesions with those already healed, i.e. hepatic scarring. The potential bacterial aetiology of hepatic scarring is suggested as its risk increases with the presence of pyaemia – suggesting that both pathologies may be associated with *Arcanobacterium pyogenes*. In addition, hepatic scarring appears interrelated with peritonitis, which is typically present in systemic infections by *Haemophilus parasuis* (responsible for Glasser's disease) or *Streptococcus suis* (Brown et al., 2007; Reams et al., 1994). These latter infectious agents would also explain the positive association between peritonitis and pericarditis. Likewise it was observed that when pleurisy was absent the chance of being peritonitis free increased.

Severe pneumonic pasteurellosis is typically manifested by abscessation and thoracic wall adherences (Pijoan C., 2006) which explains the associations detected between pleurisy and abscess. Conversely, absence of pneumonia is associated with lower levels of abscesses. High batch prevalence of enzootic pneumonia-like lesions is interrelated to high levels of pleurisy, which is an expected finding as both respiratory conditions share common husbandry risk factors (Sanchez-Vazquez et al., 2010a) and *Mycoplasma hyopneumoniae* (main pathogen for enzootic pneumonia) contributes to the occurrence of pleurisy (Enoe et al., 2002). This latter association may reflect the presence of poor health levels, particularly in the control of respiratory diseases. Alternatively, batches with mild or moderate levels of pleurisy appear more likely to be free of enzootic pneumonia, pericarditis and abscess, reflecting perhaps high health batches. Papular dermatitis is associated with the presence of milk spots, both being parasitic conditions. This association could reflect poor parasitic control strategies for some producers and highlights the fact that, even with current systems of production, parasitism is still neglected by some sectors of the industry. These results could be used to optimise abattoir inspection strategies. For example, when papular dermatitis is detected in the pigs (e.g. during the ante mortem inspections) the meat inspectors should place more emphasis in the liver inspections of those batches. This would be a proxy for the implementation of risk based surveillance abattoir polices that could optimise the use of industry and government resources (Stark et al., 2006).

Presence of pyaemia in the batch is associated with presence of tail damage. This latter pathology is known to be involved in early stages of the pathogenesis of pyaemia, by facilitating an entry access for bacteria (Huey, 1996). At pig level these two lesions might not coexist simultaneously due to the time gap between the tail damage and the development of the pyaemia (Huey, 1996), but a batch level investigation may have assisted to find such association. The approach used in this study, investigating batch level prevalence, not only maintains coherence with the nature of pig production, but would have also assisted in the identification of any association when two pathologies may be part of the same causal pathway (e.g. milk spots and hepatic scarring). In this scenario it is likely that the pathologies do not coexist in the same pig, therefore pig level investigation would be an inefficient way of exploring their association. Furthermore, pathologies presented in a mild form or during the healing process can be missed in the abattoir inspections;

whereas if they are present in more than one pig, the chance of being detected by the abattoir assessors increases leading to a more adequate batch level classification.

4.2 Clustering in the structure of data

In this study the impact on the analyses of the potential clustering structure in the data has been mitigated by modelling the data at batch level. Batch is typically the lowest and likely the strongest level of clustering present in abattoir data (Goodwin-Ray et al., 2008), particularly in health scheme pig abattoir data (Sanchez-Vazquez et al., 2010a; Sanchez-Vazquez et al., 2010b). It is also arguable that for the type of analyses presented – particularly the multi-dimensional aspect– clustering is of far less concern than in other types of traditional statistical analyses. For other potential levels of clustering to be an issue, e.g. on-farm (or abattoir or season), this would require that on different farms the proportion of batches which have, for example, {lesion A present given that lesion B is present and lesion C is not present and lesion D is present and so on...} are substantially different, and similarly for all the other conditional probabilities in the model. This form of "group-effect" is unlikely to be sizable after having already jointly adjusted for all the other conditions present in a batch. Hence, intuitively it could be argued that the machine learning methodology is robust to clustering, whether this is at farm/abattoir/season level. In practical terms, this assertion cannot be rigorously tested with this methodology and it should therefore be acknowledged as a potential limitation in this study.

4.3 Constraints of abattoir gross pathology data

The different pathologies were presented in this paper with their most typical cause (Table 1) and although some of them, i.e. EP-like lesion, milk spots and papular dermatitis, can be considered good proxies for specific pathogens (Cargill et al., 1997; Meyns et al., 2011; Sorensen et al., 2006; Stalker and Hayes, 2007), none of them are strictly pathognomonic. The data obtained from abattoir monitoring carried out by the health schemes offered here a unique opportunity to explore the associations between these relevant pig pathologies. The presence of operator bias across the assessors, affecting the gross pathology classification cannot be absolutely ruled out, but the definition of the lesions did not change during the period included in our study. Additionally, the health schemes organise training and refresher days for the veterinarians and conduct internal comparisons on the same pigs assessed by different veterinarians, aiming to maintain assessor consistency over time.

The results from this study are applicable to the whole study population, i.e. those farms participating in the pig health schemes, and particularly to those units that submitted several batches of pigs over the time period included in the study. Additionally, the results could be extrapolated to the population of British pig commercial units, as the assessments carried by the health schemes are considered representative of the British commercial sector (Sanchez-Vazquez, 2011).

4.4 Further discussion on the structure discovery approach

The multi-dimensional machine learning methodology presented is well suited for investigating multiple associations between pathologies generating hypothesis about potential interrelationships. Linear models and their generalizations, for example, would have required designating one variable as a response and modelling the rest as a set of independent predictors. Multivariate techniques like principal component and factor analyses utilise dimension reduction to facilitate the identification of uncorrelated subgroups of variables (i.e. principal components and factors). In contrast, machine learning structure discovery does not reduce the dimensions of the data and its graphical nature allows for ready interpretation of all associations present. In this study, a small variable domain – ten pathologies studied in 14 variables – is modelled with a substantial amount of data, providing the ideal scenario for structure discovery multivariate analyses (Friedman and Koller, 2003).

4.5 Conclusions

The application of novel multi-dimensional machine learning methodology provided new insights into how typical pig pathologies are interrelated at batch level, assisting in elucidating theories on their biological associations. The results from this study could be also used to optimise abattoir inspection utilising risk based surveillance strategies. The methodology presented is a powerful hypothesis-generating exploratory tool, applicable to wide range of studies in veterinary research.

5 Authors' contributions

MJSV conceived the study, carried out the statistical analyses and drafted the manuscript. FIL contributed to the conception of the study, wrote the statistical software required and assisted in drafting the manuscript. MN participated in its design and helped to draft the manuscript. SAE participated in its design and coordination and helped to draft the manuscript. GG helped to review the manuscript. All authors read and approved the final manuscript.

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Supplementary material

Data derived batch categorization for enzootic pneumonia and pleurisy.

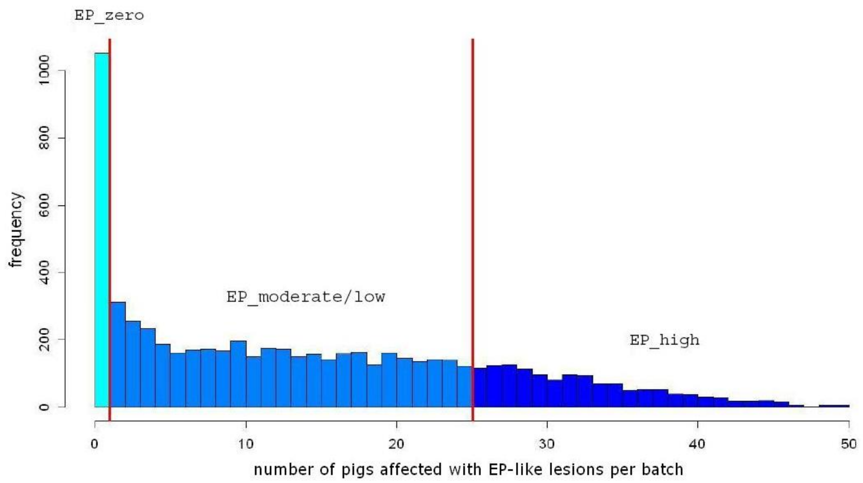

Figure 1 (Supplementary material): Histogram of the number of pigs affected with EP-like lesions per batch (all batches consisted of 50 pigs inspected). The data are grouped in three categories. A distinctive section of the batches was reported with zero prevalence (EP zero). For the positive batches two additional groups were created, those with less/equal half (25) of the pigs affected (moderate/low prevalence) and those with more than half of the pigs affected (high prevalence).

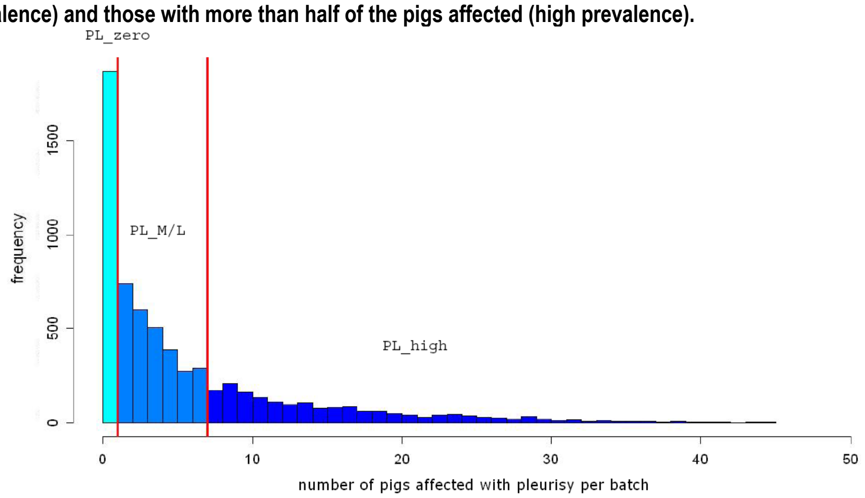

Figure 2 (Supplementary material): Histogram of the number of pigs affected with pleurisy per batch (all batches consisted of 50 pigs inspected). The data are grouped in three categories. A distinctive section of the batches was reported with zero prevalence (PL Zero). For the positive batches a drop identified in the histogram when more than seven pigs were affected with pleurisy was used as a data derived cut-off point to group the batches, thus: less or equal to seven pigs affected (moderate/low prevalence) and more than seven pigs affected (high prevalence).

Chapter VIII

Discussion

1 Summarizing discussion

1.1 Overview

This thesis gives a good account of the potential use of the information provided by private abattoir initiatives as a source of animal health data for epidemiological investigations in finishing pigs. This was the first time that the information collected by the British pig health schemes was utilized to perform epidemiological analyses adding an extra value to this information initially collected for other purposes. As discussed in Chapter II, the British Pig health schemes have become one of the most important tools available to British farmers and their veterinarians for monitoring and tackling important health problems affecting efficiency of production and/or animal welfare. The producers and their veterinarians use the feed-back from the health schemes to assess vaccine and worming interventions. These reports not only increase the awareness of producers and their veterinarians on individual herd problems but also allow the comparison of herds. Comparison of own herds with the industry as a whole would help to motivate an intention to control diseases, as was suggested by the socio-ecological model on farmers' attitude to control diseases proposed by Ellis-Iversen and others (2010).

1.2 Risk factors

The collective use of abattoir reports from the British pig industry is utilized in Chapters III and IV of this thesis to identified husbandry practices that are associated with the prevalence of enzootic pneumonia-like lesions, pleurisy and milk spots in batches of slaughtered pigs. Thus, in Chapter III, this thesis shows how the use of solid floors with bedding seemed to be protective for respiratory diseases and could be due to the fact that the use of bedding material could be beneficial to insulate the pig from the floor temperatures (Stärk; 2000). However, in this case, it is also plausible that this association is a reflection of the nature of the building characteristics or the type of production. In Great Britain, a considerable number of farms using solid floors with bedding are involved in multisite all-in-all-out production systems with subsequent benefits on pathogen transmission control. Those herds that have reported all phases of production to be indoors had a lower risk of pleurisy compared with those that have some stage of production outdoors. Extreme external temperature fluctuations could make outdoor pigs more susceptible to respiratory diseases (Done, 1991).

On the other hand, Chapter IV shows that husbandry practices that appear as risk factors for respiratory diseases influence in a different way the presence of ascariosis. Thus, pig husbandry practices, such as the use of bedding as floor bedding, and outdoors production pose a risk for the development of milk spots liver, evidencing the fact that those surfaces facilitate the endurance of ascaris eggs and therefore the survival of ascariosis. The use of straw bedding and outdoor production are growing husbandry practices within the pigs industry in response to an increasing demand for welfare friendly pork. Therefore, our results have notable relevance for the industry indicating that particular attention needs to be paid to helminth control in these types of the production system.

1.3 Time-series

This thesis also explores in Chapters V and VI the distribution over time of the prevalence of enzootic pneumonia–like lesions and milk spots through application of seasonal-trend decomposition based on loess (STL). STL methodology helped to robustly identify the trend and seasonal pattern for these two lesions in finishing pigs in England, maintaining transparency in the explorations to identify the sources of variation in the time-series (i.e. the trend, the seasonality and a remainder). In Chapter V, the GLMM (performed in parallel to the STL analyses) identified a significant quadratic trend, which was described by STL as a decline in the occurrence of EP-like lesions between 2006 and 2008 (the first three years of BPHS), followed by a period of increasing prevalence. The initial prevalence reduction detected could, in principle, be attributed to the impact of the scheme on the overall health of the pig units. Veterinarians reacted to the feedback received on the prevalence of EP-like lesions, implementing measures to reduce it. These measures were conceivably extended to BPHS non-member herds, as was discussed in Chapter II. The reason behind the increasing trend over the last three years studied (which also corresponded to a more marked seasonal pattern) is unclear, but it could reflect a relaxation in the use of *Mycoplasma hyopneumoniae* vaccines. The STL and GLMM results show the prevalence of EP-like lesions increasing at the end of the year (November and December) and declining in summer (July), a trend particularly obvious over the last three years. Given that the life-span of EP lesions is at least two months, and that it could be detected as early as two weeks after infection (Caswell and Williams, 2007), the November-December peaks may reflect farm challenges occurring across the whole autumn (from September to December). Done (1991) explained how housed pigs may have poorer air quality due to reduced housing ventilation over colder months in the trade-off to maintain indoor temperatures; a practice which may lead to an increase in the incidence of pneumonia.

The STL time series investigation for milk spots livers is presented in Chapter VI. The overall trend on milk spots livers for members was maintained across the monitoring period (2005-2010). Despite the members and their veterinarians receiving feed-back from the abattoir results, only a mild appreciable reduction in prevalence (after an initial worsening) was evident. Perhaps this level reflects an "as good as it gets" position on the control of this parasite with current strategies in the English production system. The STL results show the prevalence of milk spot livers increasing at the end of summer/ beginning of autumn and declining in winter/spring. This pattern is explained by the development of *A. suum* eggs associated with warmer temperatures (Wagner and Polley, 1999). Such a clear seasonal pattern serves to illustrate (overall) insufficient control of the parasite.

1.4 Co-dependencies

Bayesian structure discovery was applied in Chapter VII to identify co-dependencies between pig pathologies. Applying this methodology to the data comprising of the typical pathologies present in slaughtered finishing pigs has led to an easy to interpret, highly visual, and statistically robust output: a network in which the main associations between the pathologies are easily identifiable. Pathologies potentially associated with septicaemia (e.g. pericarditis, peritonitis) appear interrelated, suggesting on-going bacterial challenges by pathogens such as *Haemophilus parasuis* and *Streptococcus suis*. Furthermore, the results reveal more information on the nature of hepatic scarring which is interrelated with both milk spot livers (*Ascaris suum*) and bacteria-related pathologies. The results presented in Chapter VII could be used to optimise abattoir inspection strategies, and thus for example, when papular dermatitis is detected in the pigs (e.g. during the ante mortem inspections) the meat inspectors should place more emphasis in the liver inspections of those batches. This would be a proxy for the implementation of risk based surveillance abattoir polices that could optimise the use of industry and government resources.

1.5 Main caveats

One of the main caveats discussed in the different Chapters comprising the core of this thesis is in general the potential lack of accuracy of the abattoir data. The health schemes only work with a small number of pathologies focused on detailed inspection which is presumed to have good sensitivity and specificity since a similar inspection system, also focused on a limited number of organs and pigs, was found to have good classification characteristics (Enoe et al., 2003). The presence of operator bias affecting the gross pathology classification over time cannot be ruled out, but seems unlikely to happen. Health schemes organise training and refresher days for the veterinarians and conduct internal comparisons on the same pigs assessed by different veterinarians, aiming to maintain assessor consistency over time. On the whole, any imperfection in the scoring in such investigation could be considered randomly distributed.

Other potential problem associated with abattoir data is disease underreporting due to the healing and resolution of the pathology by the time of the slaughter, since the gross lesions assessed in the schemes persist for a limited time span. Thus, other work has shown that chronic pleurisy could only be detected for up to three months (Sorensen et al, 2006) and milk spots only persisted for a month following infection (Stewart and Hoyt, 2006). Therefore, lesions associated with early challenges in the life of the pigs will not be detectable in the abattoir and cannot be monitored by the schemes. The same is true for incipient disease challenges showing little pathological changes. Furthermore, those animals that suffer a pathological condition on the farm and do not make it to the abattoir (i.e. if they die) will not be represented in the post mortem inspection contributing to an underreporting in the prevalence of the condition.

2 Further discussion on potential improvements on official abattoir inspections in Great Britain

This thesis provides several examples of the use of abattoir data for monitoring animal health in finishing pigs. Under the on-going review of the official resources to make them more cost-effective (Ambler et al., 2010), abattoir data give an opportunity to improve animal health data sources for disease monitoring. Therefore, incorporating animal disease monitoring to the public health purpose would potentially add more value for money to the official inspections services. The private initiatives sourced for this thesis provide guidance on which aspects of the official abattoir inspection in Great Britain could be improved.

While both private abattoir inspections initiatives and those carried out under official routine inspections present some commonalities in their design, a considerable gap still exists between their services, since these two systems have very distinctive objectives. The official inspection aims mainly to warrant food safety (public heath), while the industry initiatives are essentially focused on monitoring animal health. The examples given in this thesis have demonstrated the potential for animal health monitoring that lies within abattoir inspections, highlighting an area for improvement in the current official strategy. In Great Britain, the principal role of the government inspections on safeguarding food safety could be adopted to fulfil the additional purpose of monitoring animal health, by incorporating the identification and reporting of those conditions that are relevant for the pig producers.

2.1 Improving inspectors' performance to achieve detailed inspection

The British pig health schemes investigate a small number of pathologies while government inspections in Great Britain look for a larger number of abnormalities/pathologies in each of the species. By looking at a reduced number of animals and pathologies, the industry schemes achieve a more accurate identification of the pathologies, as the characteristics of the abattoir inspections are expected to improve (better sensitivity) with detailed inspection (Enoe et al., 2003). Current government inspections do not fit within the industry interests, as their lesion classification lacks a good case definition. For example, in the pig inspection, current government inspections report the presence of "pneumonia" (with or without abscess), while the health schemes report three different types of pneumonic lesions (i.e. enzootic-pneumonia-like lesions, pleuropneumonic lesions and viral-like pneumonia). It would be necessary to review the number of abnormalities to be recorded and choose those that would be feasible to identify with minimal misclassification, which are easily recognisable by the different inspectors (both veterans and inexperienced) and are relevant and meaningful to the pig producers (e.g. those associated with particular diseases, or that reflect potential animal welfare problems or poor productivity).

After reviewing the number of abnormalities to be detected at post-mortem inspection it would be necessary to implement a training programme which warrants assessors' ability to recognise the lesions and consistency in the recording of the pathologies across all inspectors. Periodic refresher days would also be required to maintain the criteria over time. In the health schemes, recruitment of assessors with adequate background to carry out the inspection in pigs is essential; therefore, virtually all assessors are pig veterinarians. Moreover, each assessor, before starting, undergoes a training to learn to identify and record the pathologies in the way that is required by the schemes. This training is repeated annual.

2.2 Optimise electronic data flow

Another matter is the electronic recording and transfer of information. Health schemes further utilise an electronic recording system for the detected lesions in the abattoir line. This system is automatically linked to a centralised database where the information is pooled and reports are created for participating producers and affiliated veterinarians. By contrast, the British government recording system does not reach the standard demanded by the producers (i.e. poor batch identification with potential misattributions of disease status to wrong batches, information not electronically recorded on the abattoir line). Government authorities would need to review the infrastructure that supports the recording and the reporting system to allow reliable recording and efficient reporting to the producers and veterinarians. A minimum requirement for the recording systems is to be able to operate at the abattoir inspection line and allow attributing the abnormalities detected for a particular animal or batch of animals. The central database system for condemnation records needs to be capable of integrating the results from the different inspections (and different abattoirs) and of providing fast feed-back to the stakeholders involved (e.g. abattoir operator, farmers, etc.) by both electronic (email) and postal reporting. The improvements referred to in this section are already in progress, with the development of two government initiatives: Food Chain Information (FCI) and Collection and Communication of Inspection Results (CCIR) (Food Standard Agency, 2012).

2.3 Allocating costs between industry and government

A key question that emerges regarding any improvements to the official inspection services is who pays. In Great Britain so far, the cost of the system is shared between the government and the industry – with this latter burden of payment contributions falling mainly onto abattoir operators. It is likely, however, that in the near future the industry contribution will be increased and the burden of the cost may be spread to other stakeholders including producers and consumers (i.e. meat buyers). Given this, it is important to focus this discussion on defining what aspects of inspections are a public good and which are a private good, and to determine any spillovers associated with abattoir inspections, to identify who (government/ industry) should pay what (Ahuja, 2004).

Meat hygiene inspections were traditionally considered a public good to be financed publicly. Behind the meat hygiene inspections sits the maxim of protecting public health; that is, meat inspection activities reduce the level of carcass contamination and avoid the entry into the human food chain of unfit meat with a subsequent reduction on the episodes of food-borne diseases. Given this perspective, food safety is a type of public good (Holden, 1999; Ahuja, 2004) and government needs to contribute to this monitoring. This assumption, however, has been challenged over the last decade. For instance, it could be argued that the principle of low excludability – applicable to indivisible goods from which all citizens benefit and typically used to identify public goods (Holden, 1999) – is not fully applicable in the case of meat inspections since a proportion of the taxpayers make no use of it. This is particularly relevant, in those countries with high numbers of "not meat-eaters" like UK, where 7% of the population is considered to be vegetarian (Pollard et al., 2002). In this context, there is support for the idea that the livestock industry should contribute to the cost of inspections (Holden, 1999).

Animal disease surveillance could also, in principle, be regarded as a public good. Not all diseases, however, have the same relevance for national economy. With some exceptions (e.g. foot and mouth disease outbreak in UK 2001 (Gibbens et al., 2001)), abattoir disease monitoring is usually focused on subclinical endemic diseases that affect animal production traits efficiency (Chapter II). These are non-regulatory animal health issues for which the allocation of public funding is in general small and the costs of surveillance are mainly met by the industry (More, 2008). In this context, a cost-sharing arrangement between government and industry could be established along a gradient depending on the relevance (as a public good) of the disease; this follows the principle applied in the Netherlands and Australia of "who benefits pays" (More, 2008).

2.4 Conclusion

The British pig health schemes inform individual producers and their veterinarians of the occurrence of pathological conditions affecting their pig herds. Additionally, they offer the added-value of providing animal health abattoir data to perform epidemiological analyses. Official inspections also enclose an important potential as a source for animal health data. Both government and industry in Great Britain would benefit from a more integrated approach to abattoir inspection. Government needs to establish and maintain strategies to ensure food safety through meat inspection, and needs to contribute financially to this public good. Moreover, the benefits gained from animal disease surveillance (also partly considered a public good) warrant the use of government resources in meat inspection. The industry, as the main beneficiary of an improved animal health monitoring system, should pay proportionally based on the externalities provided by this system, with farmers and veterinarians receiving results on subclinical pig diseases from the abattoir.

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Summary

Routine post-mortem inspections at slaughter are enforced by governments worldwide to maintain food hygiene standards and to ensure food safety in meat. Through these systems, several pathologies and abnormalities are detected and those affected offal and carcasses (or their parts) are condemned accordingly. In parallel, the industries of a number of countries have developed their own abattoir-based health schemes. These programs provide an integrated system to optimise the post-mortem pathological detection and the reporting of abattoir health information which is widely disseminated to both participating producers and veterinarians, providing them with the knowledge on the disease occurrence in their herds. In Great Britain, as it is explained in the Second Chapter of this thesis, two initiatives have been implemented by the pig industry – Wholesome Pigs Scotland (WPS) and BPEX Pig Health Scheme (BPHS).

This thesis brought together existing information on abattoir animal health from British industry, utilizing records for pig pathologies investigated by the health schemes. In short, this thesis aims to identify disease determinants for three major pig abattoir conditions, including the description of temporal disease patterns. This thesis contributes to demonstrate the potential of abattoir records as a source for animal health data by exploring examples of their utilization for disease monitoring.

Enzootic pneumonia-like (EP-like) lesions, pleurisy and ascariosis (identified through the presence of milk spot livers) are the three most prevalent conditions reported by the British pig health schemes, and their presence are associated with reduction in performance traits and with increasing productions costs and abattoir processing. This thesis utilises the information from the British pig health schemes (from 2005 to 2007) to identify determinants for these three major pig conditions. Thus, it combined records on EP-like lesion and pleurisy (for the Third Chapter), and milk spots (for the Fourth Chapter), from 129,819 slaughtered pigs with information from the farms of origin in order to identify those production characteristics that may influence the prevalence of these lesions. Five hundred and five farms participating in the health schemes were recruited using the relevant epidemiological information available in national quality assurance programmes: pig stocking levels; feeding practices; housing systems and geographical location. For EP-like lesions and pleurisy, multivariable generalized linear mixed models were used and a multivariable beta-binomial model for milk spots, allowing for clustering at batch level.

The result for the Third Chapter shows that geographical location of the finishing unit appeared to be a statistically significant risk factor for EP-like lesions and pleurisy; the odds of a slaughtered pig from South West of England and Wales being reported as having EP-like lesion is 4.22 times higher, 95% confidence intervals (CI) 3.23-4.84, than the odds of a pig from Scotland. Also the type of floor appeared as a potential risk factor for the presence of EP-like lesions and pleurisy. Thus, those farms using solid floors with bedding seemed to have a lower risk of EP-like lesions (OR 0.79, 95% CI 0.66-0.86) compared to those not having solid floors. Similarly, those farms using solid floor with bedding appear to have a lower risk of pleurisy (OR 0.71, 95% CI 0.64-0.79) than those not using it. The use of bedding material could be beneficial to insulate the pig from the floor temperatures; also, this association could be a reflection of the nature of the building characteristics since partly slatted flooring is more common in 20-30 year old buildings with low ceilings and poorer ventilation, increasing the risk of respiratory conditions.

For the Four Chapter, we observed that for milk spots, solid floor with bedding appeared as a risk factor, OR 1.52 (95% CI 1.26-1.85). Those herds that had all the stages of production indoors appeared to be at lower risk of milk spots (OR 0.4, 95% CI 0.32-0.49). Changes were detected within year, with higher risk of milk spots in the period from July to December compare to the first half of the year OR 1.17 (95% CI 1.02-1.35). Overall this study suggests that those husbandry practices facilitating optimal levels of hygiene posed lower risk of milk spots, potentially reflecting low levels of ascariosis. Outdoor production systems and the use of straw bedding, both of which are expanding husbandry practices, require major attention with regard to helminth control.

Time-series analyses were conducted, as part of the Fifth and Sixth Chapters, to identify trend and the presence of seasonal variations for EP-like lesions and ascariosis to support industry led measures to monitor and control these pathologies. For visual analytics, the monthly prevalence for EP-like lesions (from July 2005 to June 2011) and for milk spots (from July 2005 to December 2010) were modelled using STL, a seasonal-trend decomposition method based on locally-weighted regression. A binomial generalised linear mixed-effects model (GLMM), accounting for clustering at batch level, was used to test the significance of the trends and seasonal patterns identified. Over 12,000 pigs in average were assessed per month across 12 pig abattoirs over the studied periods.

In the Fifth Chapter, a trend toward reduction in the prevalence of EP-like lesions during the first three years of BPHS, followed by an increasing trend, was identified with STL. This feature was consistent with the presence of a statistically significant positive quadratic term ("U" shape) as identified using the GLMM inference model. November and December appeared in the STL explorations as higher seasonal peaks of the occurrence of EP-like lesions. These two months had a significantly higher risk of this disease, with July taken as baseline. For the Sixth Chapter, a mild overall decrease in the prevalence of milk spots over time was identified as well as a seasonal variation which showed peaks in summer and at the beginning of autumn. September and October were the two months which had the highest (significant) prevalence compared with March, the month with the lowest prevalence (and taken as the baseline). The results from these time series analyses illustrate EP-like lesions and ascariosis as persistent problems in current farm production.

Usually, more than one pathology coexist in a pig herd although it often remains unknown how these different pathologies interrelate to each other. The Seventh Chapter of this thesis aimed to determinate how these abattoir conditions are interrelated between them and related to others. Identification of the associations between different pathologies may facilitate an improved understanding of their underlying biological linkage, and support the veterinarians in encouraging control strategies aimed at reducing the prevalence of not just one, but two or more conditions simultaneously. Multi-dimensional machine learning methodology was applied to the records from 6,485 batches of slaughtered finishing pigs to identify co-dependencies between the three abattoir pig pathologies studied in the first Chapters of the thesis and another seven typical pathologies reported by the health schemes. The results of the network indicate that pathologies potentially associated with septicaemia (e.g. pericarditis, peritonitis) appear interrelated, suggesting on-going bacterial challenges by pathogens such as *Haemophilus parasuis* and *Streptococcus suis*. Furthermore, the results reveal more information on the nature of hepatic scarring which is interrelated with both milk spot livers (*Ascaris suum*) and bacteria-related pathologies.

This thesis contributes to demonstrate the potential of combining animal health abattoir data to perform epidemiological analyses which may lead the industry to a better understanding of how the farm characteristics, geographic location and temporal distribution could influence the prevalence of EP-like lesions, pleurisy and ascariosis. The results from this thesis were reported back to the pig industry and other associated stakeholders.

The British pig health schemes inform individual producers and their veterinarians of the occurrence of pathological conditions affecting their pig herds. Additionally, they offer the added-value of providing nation-wide disease monitoring information and have the potential to be a useful surveillance tool for enzootic pig conditions. Official inspections also enclose an important potential as a source for animal health data which could offer its full potential if the inspections methodology and criteria to identify the pathologies were standardised, the recording was done accurately and there was a system to collect the information and pass it on, in an efficient fashion, to other stakeholders. Both government and industry would benefit of these improvements in the official abattoir inspection system; the former by reinforcing a public good (i.e. public health and national animal disease monitoring) and the latter by getting the externalities (with farmer and veterinarians receiving the feed-back on the level of pig disease detected in the abattoirs), this symbiotic scenario grants an opportunity to cost sharing the maintenance of the abattoir inspections.

Samenvatting

Internationaal leggen overheden gestandaardiseerde postmortem inspecties op aan slachthuizen om normen voor voedselhygiëne te handhaven en de voedselveiligheid van vlees te waarborgen. Via deze systemen komen diverse pathologische afwijkingen aan het licht en de aangedane organen en karkassen (of delen ervan) worden dienovereenkomstig afgekeurd. Parallel hieraan hebben de bedrijfstakken in een aantal landen hun eigen gezondheidsprogramma's voor slachthuizen ontwikkeld. Deze programma's voorzien in een geïntegreerd systeem dat is bedoeld om de postmortem detectie van pathologische afwijkingen en de rapportage hiervan vanuit slachthuizen te optimaliseren. Deze informatie wordt breed verspreid onder zowel deelnemende producenten als dierenartsen, die zo op de hoogte worden gesteld van bij hun dieren aangetroffen afwijkingen. In Groot-Brittannië, zoals in hoofdstuk 2 van dit proefschrift wordt beschreven, heeft de varkensindustrie twee initiatieven ontplooid: Wholesome Pigs Scotland (WPS) en BPEX Pig Health Scheme (BPHS).

In dit proefschrift is bestaande informatie van de Britse industrie over de gezondheid status van varkens vanuit slachthuisgegevens samengebracht. Hierbij is gebruik gemaakt van gegevens over karkasafwijkingen voortkomend uit de gezondheidsprogramma's. Kort gezegd wordt in dit proefschrift getracht ziektedeterminanten voor drie belangrijke varkensaandoeningen te identificeren op basis van slachthuisinformatie, inclusief de beschrijving van ziektepatronen over de tijd. Dit proefschrift wil laten zien welk potentieel slachthuisgegevens bieden als bron van informatie over de gezondheid van dieren door voorbeelden van het gebruik van deze gegevens voor ziektemonitoring te verkennen.

Enzoötische-pneumonieachtige (EP-achtige) laesies, pleuritis en ascariose (geïdentificeerd door de aanwezigheid van witte vlekken, 'milk spots', in de lever) zijn de drie meest voorkomende aandoeningen die binnen de Britse varkensgezondheidsprogramma's worden gemeld. Deze pathologische aandoeningen gaan gepaard met een verlaging van technische resultaten op het vleesvarkensbedrijf en een toename in kosten voor slachthuisverwerking. In dit proefschrift wordt allereerst de informatie van de Britse varkensgezondheidsprogramma's (van 2005 t/m

2007) gebruikt om determinanten voor deze drie belangrijke varkensaandoeningen te identificeren. Zo worden gegevens over EP-achtige laesies en pleuritis (hoofdstuk 3) en milk spots (hoofdstuk 4) van 129.819 geslachte varkens gecombineerd met informatie over de bedrijven van oorsprong om de productiekenmerken te identificeren die van invloed kunnen zijn op de prevalentie van deze laesies. Er werden vijfhonderdvijf aan de gezondheidsprogramma's deelnemende bedrijven geworven gekoppeld met relevante epidemiologische informatie die in nationale kwaliteitsbewakingsprogramma's beschikbaar was: de grootte van de varkensbezetting, voersystemen, huisvestingssystemen en geografische locatie. Voor het voorkomen van EP-achtige laesies en pleuritis werden multivariate gegeneraliseerde lineaire gemengde modellen gebruikt en voor milk spots een multivariaat bèta-binomiaal model, rekening houdend met clustering op batchniveau.

Het resultaat van hoofdstuk 3 laat zien dat de geografische locatie van het vleesvarkensbedrijf een statistisch significante risicofactor voor EP-achtige laesies en pleuritis bleek te zijn; de kans dat bij een geslacht varken uit het zuidwesten van Engeland en Wales EP-achtige laesies worden gevonden, is 4,22 maal groter, met een 95% betrouwbaarheidsinterval (BI) van 3,23-4,84 dan bij een varken uit Schotland. Gemodelleerd bleken bedrijven met dichte vloeren en strooisel een lager risico op EP-achtige laesies te hebben (OR 0,79 95% BI 0,66-0,86) in vergelijking met bedrijven die geen dichte vloeren hadden. Bedrijven met dichte vloeren en strooisel bleken eveneens een lager risico op pleuritis te hebben (OR 0,71 95% BI 0,64-0,79) dan bedrijven met roostervloeren. Het gebruik van strooisel zou gunstig kunnen zijn omdat het varkens beschermt tegen de vloertemperatuur. Dit verband kan ook voortkomen vanuit andere gebouwkenmerken, omdat gedeeltelijke roostervloeren vaker voorkomen in gebouwen van 20-30 jaar oud met lage plafonds en slechtere ventilatie, wat het risico op ademhalingsaandoeningen verhoogt.

In hoofdstuk 4 wordt beschreven dat dichte vloeren met strooisel een risicofactor voor milk spots zijn, OR 1,52 (95% betrouwbaarheidsinterval (BI) 1,26-1,85). Varkens die in alle productiefasen op stal werden gehouden, bleken een lager risico op milk spots te hebben (OR

0,40 95% BI 0,32-0,49). Er was variatie in prevalentie over het jaar, waarbij het risico op milk spots in de periode van juli t/m december hoger was dan in de eerste helft van het jaar, OR 1,17 (95% BI 1,02-1,35). Over het geheel genomen wijst dit onderzoek erop dat bij varkenshouderijsystemen die een optimale hygiëne vergemakkelijken, het risico op milk spots lager is, wat mogelijk overeenkomt met minder gevallen van ascariose. Bij productiesystemen in de open lucht en met gebruik van ligstro, welke allebei in toenemende mate worden toegepast, is veel aandacht voor wormenbestrijding nodig.

Ter ondersteuning van door de industrie getroffen maatregelen om aandoeningen te monitoren en onder controle te houden zijn tijdreeksanalyses uitgevoerd (hoofdstuk 5 en 6) om trends en seizoen variaties voor EP-achtige laesies en ascariose te identificeren. Ten behoeve van visuele analyse werd de maandelijkse prevalentie van EP-achtige laesies (van juli 2005 t/m juni 2011) en van milk spots (van juli 2005 t/m december 2010) gemodelleerd met behulp van de decompositiemethode STL (Seasonal-Trend Decomposition Procedure Based on LOESS [Locally Weighted Regression]). De significantie van de geïdentificeerde trends en seizoen patronen is getest met behulp van een GLMM (Generalised Linear Mixed-effects Model) met binomiale verdeling, rekening houdend met clustering op batchniveau. In de bestudeerde perioden werden gemiddeld meer dan 12.000 varkens per maand beoordeeld in 12 varkensslachterijen.

In hoofdstuk 5 wordt met behulp van STL een dalende trend in de prevalentie van EP-achtige laesies in de eerste drie jaar van BPHS geïdentificeerd, gevolgd door een stijgende trend. Dit kenmerk was consistent met de aanwezigheid van een statistisch significante positieve kwadratische term ('U'-vorm) zoals geïdentificeerd met behulp van het GLMM-inferentiemodel. November en december kwamen uit de STL-verkenningen naar voren als hogere seizoen pieken voor het optreden van EP-achtige laesies. Deze twee maanden hadden een significant hoger risico op het aantreffen van deze aandoening, vergeleken met juli als uitgangswaarde. In hoofdstuk 6 wordt een lichte algemene daling in de prevalentie van milk spots in de loop der tijd geïdentificeerd, evenals een seizoen variatie die pieken vertoonde in de zomer en het begin van de herfst. September en oktober waren de twee maanden met de hoogste (significante) prevalentie vergeleken met maart, de maand met de laagste prevalentie (die als uitgangswaarde werd genomen). De resultaten van deze tijdreeksanalyses illustreren dat EP-achtige laesies en ascariose aanhoudende problemen zijn in de huidige varkenshouderij.

Doorgaans komen in een groep varkens meerdere pathologische aandoeningen tegelijk voor, al blijft vaak onbekend wat de onderlinge relatie tussen deze aandoeningen is. In hoofdstuk 7 van dit proefschrift wordt getracht te bepalen hoe deze slachthuisbevindingen met elkaar en met een aantal andere aandoeningen in verband staan. Identificatie van de verbanden tussen verschillende aandoeningen kan een beter begrip van de onderliggende biologische relatie bevorderen en dierenartsen ondersteunen bij het stimuleren van bestrijdingsstrategieën gericht op verlaging van de prevalentie van niet slechts één, maar meerdere aandoeningen tegelijk. Een multidimensionale methodologie voor machinaal leren is toegepast op gegevens van 6.485 batches geslachte vleesvarkens om afhankelijkheden te identificeren tussen de drie genoemde aandoeningen bij slachthuisvarken, en nog zeven typische aandoeningen die ook vanuit de gezondheidsprogramma's worden gemeld. De resultaten van het netwerk wijzen erop dat aandoeningen die mogelijk samengaan met septikemie (bv. pericarditis, peritonitis), onderlinge samenhang vertonen, wat kan wijzen op doorlopende blootstelling aan bacteriële pathogenen als *Haemophilus parasuis* en *Streptococcus suis*. Verder geven de resultaten meer informatie over de aard van littekenweefselvorming in de lever, die in verband staat met zowel milk spot-letsels in de lever (*A. suum*) als bacterie gerelateerde afwijkingen.

Dit proefschrift wil laten zien wat het potentieel is van het uitvoeren van epidemiologische analyses op basis van gecombineerde slachthuisgegevens over de gezondheid van dieren. Deze analyses kunnen de bedrijfstak meer inzicht geven in de wijze waarop bedrijfskenmerken, geografische locatie en seizoen de prevalentie van EP-achtige laesies, pleuritis en ascariose kunnen beïnvloeden. Over de resultaten van dit proefschrift is verslag uitgebracht aan de varkensindustrie en andere betrokken belanghebbenden.

De Britse varkensgezondheidsprogramma's informeren individuele producenten en hun dierenartsen over de bij hun groepen varkens aangetroffen pathologische aandoeningen. Daarnaast hebben ze de toegevoegde waarde dat ze landelijke informatie met betrekking tot ziektemonitoring verstrekken en kunnen ze een nuttig surveillancemiddel voor enzoötische aandoeningen bij varkens vormen. Officiële inspecties hebben eveneens een belangrijk potentieel als bron van diergezondheidsgegevens en hun volledige potentieel zou kunnen worden benut als de gehanteerde methodologie en criteria voor identificatie van de pathologische afwijkingen worden gestandaardiseerd, de vastlegging accuraat wordt uitgevoerd en er een systeem is om de informatie te verzamelen en op efficiënte wijze door te geven aan andere belanghebbenden. Zowel overheid als industrie zou kunnen profiteren van zulke verbeteringen in het officiële inspectiesysteem voor slachthuizen. De overheid door versterking van een openbaar goed (d.w.z. volksgezondheid en nationale dierziektemonitoring) en de industrie door de bijkomende informatie (veehouders en dierenartsen krijgen feedback over de omvang van varkensafwijkingen die in slachthuizen zijn gedetecteerd); een dergelijk symbiotisch scenario zou de mogelijkheid openen om de kosten van slachthuisinspecties te delen.

Resumen

Los sistemas rutinarios de inspección post-mortem de los mataderos son impuestos por los gobiernos a nivel mundial para mantener las normas de higiene alimentaria y para garantizar la seguridad alimentaria de la carne. A través de estos sistemas, se detectan varias patologías y anomalías siendo decomisados en consecuencia los despojos y las canales (o sus partes) afectados. Al mismo tiempo, las industrias de varios países han desarrollado sus propios esquemas sanitarios basados en los mataderos. Estos programas proporcionan un sistema integrado para optimizar la detección de patologías post-mortem y la comunicación de la información sanitaria del matadero, que es ampliamente difundida a los productores y veterinarios participantes, proporcionándoles el conocimiento de la ocurrencia de la enfermedad en sus rebaños. En Gran Bretaña, tal como se explica en el segundo capítulo de esta tesis, dos iniciativas han sido implementadas por la industria porcina – "Wholesome Pigs Scotland (WPS)" y "BPEX Pig Health Scheme (BPHS)".

En esta tesis se ha compilado información sobre sanidad animal existente en mataderos de la industria británica, utilizando los registros de patologías porcinas investigados por los esquemas sanitarios. Fundamentalmente, esta tesis tiene como objetivo identificar los factores determinantes de enfermedad en tres patologías principales detectadas en los mataderos de cerdos, incluyendo la descripción de los patrones de variación temporal de las enfermedades. Esta tesis contribuye a demostrar el potencial de los registros de mataderos como fuente de datos de sanidad animal mediante la exploración de ejemplos de su utilización para el seguimiento de la enfermedad.

Las lesiones tipo-neumonía enzoótica (tipo-NE), pleuritis y ascariosis (identificados a través de la presencia de los hígados con manchas de leche) son las tres patologías más prevalentes reportadas por los esquemas sanitarios británicos en cerdos, y su presencia se asocia con una reducción en las características de rendimiento y con el aumento de los costes de producción y del procesamiento en matadero. En esta tesis se utiliza la información de los esquemas sanitarios porcinos británicos (del 2005 al 2007) para identificar los factores determinantes de estas tres patologías del cerdo. Así, combina registros de las lesiones tipo-NE y pleuritis (tercer capítulo), e hígados con machas de leche (cuarto capítulo), de 129.819 cerdos sacrificados, e incorpora la información de las granjas de origen con el fin de identificar las características de producción que pueden influir en la prevalencia de estas lesiones. Quinientas cinco granjas participantes en los esquemas sanitarios fueron reclutadas utilizando la información epidemiológica relevante disponible en los programas de control de calidad nacionales, tales como: el número de cerdos, las prácticas de alimentación, sistemas de alojamiento y la ubicación geográfica. Para las lesiones tipo-EP y pleuritis, se utilizaron modelos multivariables lineales generalizados mixtos y un modelo multivariable beta-binomial para los hígados con manchas de leche, teniendo en cuenta una agrupación de los datos a nivel de lote.

El resultado del tercer capítulo muestra que la ubicación geográfica de la granja de cebo, aparece como un factor de riesgo estadísticamente significativo para la lesión tipo-EP y pleuritis; así la odds de que un cerdo sacrificado procedente del suroeste de Inglaterra y Gales aparezca con una lesión tipo-EP es 4.22 veces mayor, con intervalos de confianza del 95% (IC) 3,23 a 4,84, que la odds de un cerdo de Escocia. El tipo de suelo también apareció como un factor de riesgo potencial para la presencia de lesiones tipo-EP y pleuritis. Así, las explotaciones con suelos sólidos con yacija parecieron tener un menor riesgo de lesiones tipo-EP (OR 0.79, IC 95% 0,66-0,86) en comparación con aquellos que no tenían suelos sólidos con yacija. Del mismo modo, las explotaciones con suelo sólido con yacija parecieron tener un menor riesgo de pleuritis (OR 0.71, IC 95% 0,64-0,79) que aquellos que no lo utilizaban. El uso de yacija podría ser beneficioso para aislar al cerdo de las temperaturas de suelo. Ésta asociación podría ser un reflejo de la naturaleza de las características del edificio ya que el suelo con slat parcial es más común en los edificios de hace 20-30 años, con techos bajos y ventilación pobre, aumentando el riesgo de enfermedades respiratorias.

En el capítulo cuatro, se observó que para las manchas de leche, el suelo sólido con yacija apareció como un factor de riesgo, OR 1,52 (IC 95% 1,26 a 1,85). Los granjas que tenían todas las etapas de la producción en interior parecieron estar en menor riesgo de hígados con manchas de leche (OR 0,4; IC 95% 0,32 a 0,49). Se detectaron cambios de ocurrencia en el año, con un mayor riesgo de hígados con manchas de leche en el período de julio a diciembre en comparación con el primer semestre del año OR 1,17 (IC 95% 1,02-1,35). En general, este estudio sugiere que las prácticas de manejo que facilitan la máxima higiene plantean menos riesgo de manchas de leche, lo que podría reflejar bajos niveles de ocurrencia de ascariosis. Sistemas de producción al aire libre y el uso de camas de yacija, que son prácticas que se están expandiendo en la producción porcina, requieren mayor atención en materia de control de helmintos.

Se realizaron análisis de series temporales, como parte de los capítulos quinto y sexto, para identificar tendencias y la presencia de las variaciones estacionales de las lesiones tipo-EP y ascariosis que pudieran apoyar las medidas del sector destinadas a supervisar y controlar estas patologías. Para un análisis visual, la prevalencia mensual de lesiones tipo-EP (entre julio de 2005 junio de 2011) y para las manchas de leche (entre julio de 2005 diciembre de 2010) se modelaron usando STL, un método de descomposición de estacionalidad y tendencia basado en una regresión ponderada localmente. Se utilizó un modelo binomial lineal generalizado de efectos mixtos (GLMM) permitiendo una agrupación a nivel de lote, para evaluar la significación de las tendencias y patrones estacionales identificados. En los periodos estudiados, más de 12.000 cerdos en promedio fueron inspeccionados al mes.

En el quinto capítulo, una tendencia hacia la reducción de la prevalencia de las lesiones tipo-EP durante los tres primeros años de BPHS, seguida de una tendencia creciente, fue identificada con STL. Esta característica fue consistente con la presencia de un término cuadrático positivo estadísticamente significativo (forma de "U") identificado mediante el modelo de inferencia GLMM. Noviembre y diciembre aparecieron en las exploraciones STL como altos picos estacionales de la aparición de lesiones tipo-EP. Estos dos meses tuvieron un riesgo significativamente mayor de esta enfermedad, tomado como referencia el mes de julio. En el capítulo sexto, fue identificada una leve disminución global en la prevalencia de hígados con manchas de leche, así como una variación estacional, que mostró picos en verano y al principio del otoño. Septiembre y octubre fueron los dos meses que tenían la mayor prevalencia (significativa) en comparación con el mes de marzo (el mes con la menor prevalencia y que fue tomado como referencia). Los resultados de estos análisis de series temporales ilustran como las lesiones tipo-EP y ascariosis son problemas persistentes en la producción actual de las granjas.

Por lo general, más de una patología coexisten en una nave de cerdos a pesar de que a menudo se desconoce cómo estas diferentes patologías se interrelacionan entre sí. El séptimo capítulo de esta tesis tuvo como objetivo determinar cómo estas patologías detectadas en los mataderos están interrelacionados entre sí y en relación con las demás. La identificación de las asociaciones entre diferentes patologías puede facilitar una mejor comprensión de su vinculación biológica subyacente, y apoyar a los veterinarios en el fomento de las estrategias de control para reducir la prevalencia de no sólo una, sino dos o más patologías a la vez. La metodología multidimensional de aprendizaje de máquinas se aplicó a los registros de 6.485 lotes de cerdos de engorde sacrificados para identificar codependencias entre las tres patologías porcinas estudiadas en los capítulos anteriores de esta tesis y otras siete patologías típicas reportadas a través de los esquemas sanitarios. Los resultados de la red indican que patologías potencialmente asociadas con septicemia (por ejemplo, pericarditis, peritonitis) aparecen relacionadas entre sí, lo que sugiere infecciones por patógenos bacterianos tales como *Haemophilus parasuis* y *Streptococcus suis*. Por otra parte, los resultados ponen de manifiesto más información sobre la naturaleza de la lesión identificada como cicatriz hepática que está interrelacionada con ambos: manchas de leche (*Ascaris suum*) y patologías bacterianas.

Esta tesis contribuye a demostrar el potencial de la combinación de datos zoosanitarios de los mataderos para realizar análisis epidemiológicos que pueden llevar a la industria a un mejor entendimiento de cómo las características de la granja, la ubicación geográfica y la distribución temporal podrían influir en la prevalencia de lesiones tipo-EP, pleuritis y ascariosis. Los resultados de esta tesis fueron comunicados a la industria porcina y otras partes asociadas.

Los esquemas británicos sanitarios en cerdos informan individualmente a los productores y veterinarios de la aparición de procesos patológicos que afectan sus granjas. Además, ofrecen el valor añadido de proporcionar información a nivel nacional para el seguimiento de enfermedades y tienen el potencial de ser una herramienta útil para la vigilancia de enfermedades enzoóticas del cerdo. Las inspecciones oficiales también abarcan un importante potencial como fuente de datos zoosanitarios que podría explotarse al máximo si la metodología y los criterios para identificar las patologías en las inspecciones estuvieran estandarizados, los registros se realizaran con precisión y hubiera un sistema para recopilar la información y transmitirla seguidamente, de manera eficiente, a otras partes interesadas. Tanto el gobierno como la industria se beneficiarían de estas mejoras en el sistema oficial de inspección de mataderos; el primero mediante el refuerzo de un bien público (es decir, la salud pública y el seguimiento nacional de enfermedades animales) y la segunda porque obtiene las externalidades (con los agricultores y los veterinarios recibiendo la retroalimentación sobre el nivel de enfermedad porcina detectada en los mataderos), este simbiótico escenario otorga la oportunidad de compartir el costo de mantenimiento de las inspecciones en los mataderos.

Résumé

L’inspection post-mortem systématique à l’abattoir est imposée par les gouvernements à travers le monde pour le respect des normes d'hygiène alimentaire et pour assurer la sécurité alimentaire de la viande. Grâce à ces programmes d’inspection, plusieurs pathologies et anomalies sont détectées et les abats et carcasses (ou leurs parties) affectés sont, en conséquence, saisis. Parallèlement, l’industrie d'un certain nombre de pays a développé ses propres programmes de santé basés sur les abattoirs. Ces programmes fournissent un système intégré afin d'optimiser la détection de pathologies post-mortem et la communication de l'information sanitaire obtenue depuis l'abattoir, vers les producteurs et les vétérinaires participants, en leur fournissant des renseignements sur l’état de la maladie dans leurs troupeaux. En Grande-Bretagne, comme expliqué dans le deuxième chapitre de cette thèse, deux initiatives ont été mises en œuvre par l'industrie du porc - "Wholesome Pigs Scotland (Porcs sains d’Ecosse) (WPS)» et «BPEX Pig Health Scheme (Système de Santé des porcs)".

Cette thèse a rassemblé l’information recueillie par l'industrie sur la santé animale dans les abattoirs britanniques, en utilisant les registres des maladies porcines étudiées dans le cadre des programmes de santé mentionnés ci-dessus. En bref, cette thèse vise à identifier les facteurs déterminants pour trois pathologies principales détectées dans les abattoirs de porcs, y compris la description des modèles de variation temporelle de ces maladies. Cette thèse contribue à démontrer le potentiel des registres d’abattoirs en tant que source de données pour la santé animale en explorant des exemples de leur utilisation pour la surveillance de maladies.

Les lésions type-pneumonie enzootique (type-PE), la pleurésie et l’ascaridiose (identifiée par la présence de taches blanches sur le foie ou « taches de lait ») sont les trois pathologies les plus répandues d’après les programmes de santé porcine britanniques, et leur présence est associée à une réduction des caractéristiques de rendement, ainsi qu’à l’augmentation des coûts de production et de transformation à l'abattoir. Cette thèse utilise les informations provenant des programmes de santé porcine britanniques (2005-2007) afin d'identifier les déterminants de ces trois maladies porcines. Ainsi, elle combine les enregistrements de lésions type-PE et de pleurésie (dans le troisième chapitre), ainsi que les enregistrements de taches de lait (dans le quatrième chapitre) de 129 819 porcs abattus, avec les informations des fermes d'origine, afin d'identifier les caractéristiques de production qui peuvent influencer la prévalence de ces lésions. Cinq cent cinq fermes participant à des programmes de santé ont été recrutées selon les informations épidémiologiques pertinentes suivantes, disponibles dans les programmes nationaux d'assurance qualité: le nombre de porcs, les pratiques d'alimentation, les systèmes de logement et l'emplacement géographique. Pour les lésions type-PE et pleurésie, des modèles multivariables linéaires généralisés mixtes ont été utilisés, et un modèle multivariable bêta-binomiale a été utilisé pour taches de lait, permettant le regroupement de données au niveau du lot.

Le résultat du troisième chapitre montre que l'emplacement géographique de la ferme d'engraissement est apparu comme un facteur de risque statistiquement significatif pour l'apparition de lésions type-PE et de pleurésie, de sorte que l'odds qu'un porc abattu provenant du sud-ouest de l'Angleterre et du Pays de Galles apparaisse avec une lésion type-PE est 4.22 fois plus élevée, intervalles de confiance (IC 95%) de 3,23 à 4,84, que l'odds d'un cochon provenant d'Ecosse. Egalement, le type de sol est apparu comme un facteur favorisant potentiellement la présence de lésion de type-PE et de pleurésie. Ainsi, les fermes avec des planchers solides recouverts de litière semblent présenter un risque plus faible de lésions type-PE (OR 0,79 ; IC 95 0,66 à 0,86%) que les fermes sans planchers solides recouverts de litière. De même, les fermes ayant un plancher solide recouvert de litière semblent présenter un risque plus faible de pleurésie (OR 0,71 ; IC 95 0,64 à 0,79%) que les fermes qui n'en n'utilisent pas. L'utilisation de la litière peut être bénéfique pour isoler le porc de la température du sol ; en outre, cette association peut être un reflet de la nature des caractéristiques des immeubles qui datent de 20-30 ans dans lesquels l'utilisation de plancher en caillebotis partiel est fréquente, avec des plafonds bas et une mauvaise ventilation, ce qui augmente le risque de maladies respiratoires.

Dans le chapitre quatre, nous avons constaté que pour les foies aux taches blanches, la présence de planchers solides recouverts de litière est apparue comme un facteur de risque, OR 1,52 (IC 95% de 1,26 à 1,85). Les fermes qui procédaient à toutes les étapes de production hors sol (à l'intérieur) sont apparues comme présentant un plus faible risque pour l'apparition de ces lésions (OR 0,4, IC 95% de 0,32 à 0,49). Des variations sur les événements ont été détectées dans l'année, avec un risque plus élevé de foies aux taches blanches sur la période de Juillet à Décembre par rapport au premier semestre de l'année OR 1,17 (IC 95% de 1,02 à 1,35). Globalement, cette étude suggère que les pratiques d'élevage, qui offrent un maximum d'hygiène, présentent moins de risques de foies aux taches blanches, ce qui pourrait refléter une charge d'ascaris inférieure. Les systèmes de production en plein air et l'utilisation de litières de paille, qui sont des pratiques en pleine expansion dans la production porcine, nécessitent d'une attention majeure à l'égard de la lutte contre les helminthes.

Des analyses de séries temporelles ont été réalisées, dans le cadre des cinquième et sixième chapitres, afin d'identifier les tendances et la présence des variations saisonnières pour les lésions type-PE et l'ascaridiose, afin de soutenir les mesures mises en œuvre par l'industrie pour surveiller et contrôler ces maladies. Pour une analyse visuelle, la prévalence mensuelle de lésions type-PE (de Juillet 2005 à Juin 2011) et de foies aux taches blanches (de Juillet 2005 à Décembre 2010) a été modélisée en utilisant la technique STL, une méthode de décomposition des variations saisonnières et des tendances sur la base d'une régression à pondération locale. Un modèle binomial linéaire généralisé à effets mixtes (GLMM), permettant le regroupement au niveau du lot, a été utilisé pour évaluer l'importance des tendances et des modèles saisonniers identifiés. Plus de 12 000 porcs ont été inspectés en moyenne par mois dans 12 abattoirs au cours des périodes étudiées.

Dans le cinquième chapitre, une tendance à la réduction de la prévalence des lésions type-PE au cours des trois premières années du BPEX, suivie d'une tendance à la hausse, ont été identifiées avec la technique STL. Cette caractéristique était compatible avec la présence d'un terme quadratique positif statistiquement significatif (en forme de "U") identifié par le modèle d'inférence GLMM. Novembre et Décembre sont apparus dans les explorations STL comme les pics saisonniers les plus élevés pour l'occurrence de lésions type-PE. Ces deux mois présentaient un risque significativement plus élevé pour cette maladie, Juillet étant choisi comme référence. Dans le sixième chapitre, une légère diminution globale de la prévalence des foies aux taches blanches au fil du temps a été identifié ainsi qu'une variation saisonnière qui présentait des pics en été et au début de l'automne. Septembre et Octobre étaient les deux mois qui présentaient la plus forte prévalence (significative) par rapport à Mars, le mois avec la prévalence la plus faible (et pris comme référence). Les résultats de ces analyses de séries temporelles illustrent que les lésions type-PE et l'ascaridiose sont des problèmes persistants dans les fermes de productions actuelles.

Généralement, plusieurs pathologies coexistent dans un cheptel de porcs même si souvent on ne sait pas comment ces différentes pathologies interagissent. Le septième chapitre de cette thèse a eu pour objectif de déterminer comment ces pathologies d'abattoirs sont liées les unes aux autres et avec d'autres. L'identification des associations entre différentes pathologies peut faciliter une meilleure compréhension de la relation biologique sous-jacente, et soutenir les vétérinaires dans la promotion des stratégies de contrôle pour réduire la prévalence de non seulement une, mais deux ou plusieurs maladies à la fois. Une approche multidimensionnelle d'apprentissage automatique a été appliquée aux données de 6 485 lots de porcs d'engraissement abattus, pour identifier la co-dépendance entre les trois maladies porcines étudiées dans les chapitres précédents de cette thèse et sept autres maladies typiques rapportés par les programmes sanitaires. Les résultats de ce réseau indiquent que les pathologies potentiellement associées à une septicémie (par exemple, péricardite, péritonite) sont liées les unes aux autres, ce qui suggère une infection par des bactéries pathogènes telles que *Haemophilus parasuis* et *Streptococcus suis*. Par ailleurs, les résultats révèlent d'avantage d'informations sur la nature d'une lésion identifiée comme « cicatrice hépatique » et qui est étroitement liée à la fois: foies aux taches blanches (*Ascaris suum*) et aux maladies bactériennes.

Cette thèse contribue à démontrer le potentiel de combiner les données de santé animale des abattoirs pour l'analyse épidémiologique qui peuvent donner à l'industrie une meilleure compréhension de la façon dont les caractéristiques des exploitations, l'emplacement géographique et les saisons peuvent influer sur la prévalence de lésion type-PE, de pleurésie et d'ascaridiose. Les résultats de cette thèse ont été communiqués à l'industrie du porc et d'autres partenaires.

Les programmes de santé de porcine britanniques informent individuellement les producteurs et les vétérinaires de l'apparition de pathologiques qui affectent leurs exploitations. Ils offrent aussi la valeur ajoutée de fournir des informations à l'échelle nationale pour le suivi de maladies et d'avoir le potentiel d'être un outil utile pour la surveillance les maladies enzootiques des porcs. Les inspections officielles ont aussi un potentiel important en tant que source de données sur la santé des animaux qui pourraient être exploitées au maximum si la méthodologie et les critères pour identifier les pathologies étaient harmonisées, si les dossiers étaient constitués avec précision et si il y avait un système pour recueillir et transmettre les informations de manière efficace aux autres parties intéressées. Le gouvernement comme l'industrie pourraient bénéficier de l'amélioration des programmes officiels d'inspection des abattoirs, le premier en renforçant un bien public (i.e. la santé publique et la surveillance national des maladies animales) et la deuxième par l'obtention d'externalités (avec les agriculteurs et les vétérinaires en recevant un retour sur le niveau des maladies détectées dans les abattoirs de porcs), ce scénario symbiotique fournit une occasion de partager les coûts des inspections de maintenance dans les abattoirs.

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Curriculum Vitae

Manuel J. Sanchez Vazquez graduated as a veterinarian at the Universidad Complutense (Madrid, Spain) in 1999 and since then has worked in several fields of the veterinary profession and in five different countries. He started his career working in a small animal practice in Madrid but was soon recruited (in 1999) to work as a veterinary technical adviser for a Spanish national union of farmers, COAG (based in Madrid). After that experience and a brief collaboration as an official veterinarian in the 2001 FMD episode in UK (in Worcester area), he worked (from 2001 and 2002) as a pathologist in a wild animal diseases diagnostic laboratory in Spain, Laboratorio Veterinario Sil-Ex (in Madrid), for which he was founding partner. In 2002, he returned to England and worked two years for the Meat Hygiene Service and as a poultry veterinarian (based in Exeter). In 2004, he commenced to work as a pathologist in Vetlab-IDEXX laboratories (in Horsham), and until 2006, he combined this job with a Master of Science in Veterinary Epidemiology at the London School of Hygiene Tropical Medicine and Royal Veterinary College (London). In 2007, he moved to Scotland (Inverness) to join the Epidemiology Research Unit of the Scottish Agricultural College (SAC), where he was involved in national epidemiological studies, investigating the occurrence of pig diseases utilising data generated by the industry: the results garnered from this experience form the basis of the research work included in this thesis. He was also an invited member of the committee of BPEX Pig Health Scheme and of the Scottish Pig Diseases Control Group. Whilst working for SAC, he undertook a Secondment to the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) which is part Public Health Agency of Canada (based in Guelph). In 2011, he left SAC to serve at the OIE headquarters as Deputy Head of the Animal Health Information Department (Paris, France). In this current position, he contributes to the OIE notification system and its enforcement by the countries, supervises the quality control of the disease notification reports and supports the maintenance and improvement of the World Animal Health Information Database (WAHIS/D).

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