COMBINED SPATIAL AND NETWORK ANALYSIS OF GREAT BRITAIN PIG MOVEMENT AND ABATTOIR SURVEILLANCE DATA

Final Report

To:	**BPEX**
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Executive Summary

In the last decade, the British pig industry has taken a proactive stance concerning the health and welfare of pigs. On a national level, the industry implemented two major disease monitoring tools (BPHS and WPS) to provided producers and veterinarians with valuable information on farm disease prevalence. Pig production is not a closed system restricted by geographical boundaries, however, not only neighbouring factors but also animal movements may contribute to disease transmission. As a consequence of the Foot and Mouth Disease outbreak in 2001, recording of pig movements has become a requirement and these records have become a source of surveillance data available for epidemiological analysis. This information allows the identification of the "active" pig holdings and provides information about the inter-holding contacts and their geographical location. Through the use of pig movement data and spatial and network analysis, this project aimed to identify and characterise the "active" British pig holdings regarding their demographic, spatial and network structure.

The datasets used in the project were: a) Rapid Analysis and Detection of Animal-related Risks (RADAR) dataset (government-held pig movement records, combined movements from Animal Movement Licensing System (AMLS) and Scottish Animal Movement System (SAMS), subset of movements from years 2006-2011); b) Sprod and Eprod datasets (pig movement records from 2008 from one Scottish and one English pig producer, respectively); and c) BPEX Pig Health Scheme (BPHS) and Wholesome Pigs Scotland (WPS) datasets (abattoir monitoring data, from 2006-2009, for England/Wales and Scotland, respectively). The movement data was obtained from RADAR, the producer's datasets were obtained directly from the producers, BPHS data was obtained from BPEX and WPS data from Quality Meat Scotland (QMS). The records provided by RADAR were submitted to a cleaning process and explored both for illogical and inconsistent information (e.g. correction of inconsistencies in the holding type, renaming of "Unknown", "Non-AMLS" and "Common Land" County/Parish/Holdings (CPHs) as "Farm"; removal of movements with the same CPH number in departure and destination; removal of "illogical" or irrelevant movements such as Abattoir-to-Farm or Market and Abattoir-to-Abattoir).

The datasets were compared with the objectives of quantifying: 1) the number of comparable movements between datasets; 2) the agreement between the numbers of animals reported; and 3) the number of non-comparable records. For this comparison a subset of RADAR dataset was used (2006-2009). During this exercise, systematic errors were identified and reasons for non-matching and non-agreement were found, e.g. the comparison of different

dates, the problem of aggregated data and data entry errors. The comparison was possible for only 7,724 (1%) of all RADAR movements and 74 movements were found to be absent from the RADAR dataset provided. There was an agreement in the number of animals reported in 5,605 movements (73%), the overall mean difference of animals obtained was -0.16 and 96% of the non-agreement records had differences less than 52 animals. This highlighted that the majority of the comparable movements show an agreement in the numbers reported and that only a small amount of movements were identified as under-reported for the RADAR dataset. Therefore, the RADAR dataset was considered a useful source for analysing the pig movements in GB and was therefore used for the descriptive analysis.

The description of British pig holdings regarding their demographic, spatial and network structure, over 2006 to 2011, showed that the number of holdings included in the movement database varied over the years but, overall, the farm CPHs accounted for 98.6% of all CPHs in the movement dataset. When looking at movements over the years, 70% of the movements were to abattoirs, 23% to farms and 7% to market. There was an average of 200,000 movements per year. In terms of pigs being moved, on average there were approximately 5 million pigs moved towards farms, 8 million to abattoirs and only 160,000 to markets, resulting in a total of around 14 million pigs moved per year in GB. The majority of pig farms (82%) were located in England, while Wales account for 10% and Scotland for 8%.

The farm distribution over the different GB NUTS II regions showed some regions of England had the highest density of farms per region, e.g. Cornwall and Isles of Scilly (30 farms/100 km^2) and Dorset and Somerset (24 farms/100 km^2). In Wales, the region of West Wales and The Valleys (11 farms/100 km^2), and in Scotland the northeast of the country (5 farms/100 km^2) had the highest density of farms per region. In GB, 27% of the farms had less than 5 other farms in a 3km radius, 43% had between 5 to 10; and 30% more than 10 surrounding farms. This highlights the risk for spreading airborne diseases. However, the majority of farms in Scotland (84%) had only between 1 to 5 farms in the vicinity, showing a decrease risk in terms of local spread.

From the total of 1,161,406 pig movements that occurred in GB, from 2006 to 2011 to which was possible attribute a geographic location, the departure and destination of 56% were in the same region and 97% in the same country. Movements between regions were largely observed when pigs were moved from a market to an abattoir, whereas the opposite happened when pigs were moved between markets, i.e. they tend to happened within the same region. The maximum distances travelled were observed in movements between farms (792km) and from farm to abattoir (767km). The median distance of pig movements was approximately 31km for the majority of movement types, except for movements market-to-abattoir (median=53km) and market-to-market (median=71km). Only 14% of the movements

involved distances of over 100km. The large majority of within-country pig movements occurred in England (91%) with a median of 30km and a maximum of 563km travelled. Movements between countries accounted for only 3% of the total pig movements. The majority of across GB country movements occurred from Wales to England (38%), Scotland to England (34%) and England to Wales (24%). Only a small fraction of movements occurred from England to Scotland and between Scotland and Wales.

The median batch size of the between-farm moments was equal within countries. Scotland sent larger batches to markets (8 pigs per batch) than England and Wales; abattoirs in Scotland also received larger batches (median of 18 and maximum of 668) than England (median of 10 and maximum of 299).

The number of sources (in-degree) and destinations (out-degree) was assessed for each type of CPH. The median in and out degree for farm and markets was one; the median in-degree for abattoirs was 24 for English abattoirs, 14 for Welsh abattoirs and 4 for Scottish abattoirs. Regardless of the type of movement, England always had the highest in and out degree, followed by Scotland and Wales.

With the 2008 RADAR data, the farms were categorised as “Large” when they had moved more than 1000 animals; they were categorised as “Small”, when their total number of animals moved was less than 35. The farms having the total number of animals moved in the range [35 - 1000] were considered “Medium” producers. The proportions for the totality of farm CPH (18,565) were: 2,470 (13%) “Large”, 3,486 (19%) “Medium” and 12,609 (68%) “Small”.

The higher percentage of farm to farm movements was observed between large producers and at the same time more animals were moved by these producers, with a higher median number of animals transported per movement. The large producers were also responsible for the majority of the number of movements and number of animals moved from farm to abattoir. The medium producers, on the other hand, had the higher proportion of movements between farm and gathering holdings. The small producers did not have a large number of movements or animals moved; however, there were a small number of movements from small to medium and large producers. These types of unexpected movements should be explored in order to see if they might pose a higher risk of disease transmission, or whether they are genuine movements or just errors in the database.

The movements between large producers or from large to abattoir were the ones involving the greatest distance. The small producers had the smallest distances travelled, irrespective of the type of movement.

The farm distribution was assessed by county. England had the greatest number of farms per county, followed by Wales and then Scotland. When accounting for size category in the assessment of farm distribution it was observed that the Yorkshire and Norfolk regions in

England and Aberdeenshire in Scotland were those with highest number of large producers; while Devon and Cornwall in England and Dyfed in Wales were the regions with the highest number of small producers. The medium producers were spread throughout England with a low number of farms per county and the highest numbers in Yorkshire and Devon; the number was much lower in Scotland and Wales.

The farm categorisation used considers the gross quantity of pigs that pass through a farm in one year as a rough proxy for the farm size and can therefore be used to identify the regions in which the largest/smallest producers are located and which hypothetically have more/less pigs. The total number of animals moved per year is not the best proxy for herd size for all types of production, however, e.g. when comparing a breeder unit with finisher unit, both could be considered large commercial units, but the latter might be considered large, according to the categorisation used in this report, because it will have pigs being moved in and out of the farm, whereas the former might be considered medium for only having pigs being moved out of the farm. Thus, farm categorisation should take into consideration the ratio of movements in and out to determine both the farm size as well as the likely type of production (i.e. breeder, breeder-finisher and finisher).

This project has showed the value of movement data for the characterisation of denominator data (i.e. number of active pig holdings) and the different types of producers. The results also showed that there was an interconnection between the different types of producers in terms of movements, especially for the unexpected movements between large producers (believed to belong to quality assurance schemes and therefore with a higher biosecurity) and small producers (believed to have a lower biosecurity status and therefore more prone to introduction and spread of undiagnosed disease). Furthermore, the network analysis showed that medium producers had a higher proportion of movements to small and large producers than the inverse. It is therefore plausible that medium producers may represent a bridge between the large and small producers of the pig industry, potentially allowing undiagnosed pathogen to spread throughout the industry. A risk-based approach is recommended for consideration within future monitoring programmes, particularly for exotic disease.

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Introduction

In the last decade, the British pig industry has been proactive towards the better health and welfare of pigs. On a national level, the industry implemented two major disease monitoring tools: the BPEX Pig Health Scheme (BPHS) and Wholesome Pigs Scotland (WPS). These abattoir monitoring schemes have provided the producers and veterinarians with valuable information on farm disease prevalence and, in general, have potentially contributed to an overall decreasing disease trend. Pig production, however, is not a closed system restricted by geographical boundaries; since not only neighbouring factors but also animal movements may contribute to disease transmission. As a consequence of the Foot and Mouth Disease (FMD) outbreak in 2001, pig movements have been recorded and have become a source of surveillance data available for epidemiological analysis. This information allows the identification of the "active" pig holdings and provides information about the inter-holding contacts and their geographical location. Together, the abattoir disease monitoring and the pig movement data provide an opportunity to improve knowledge of 1) the demographic, spatial and network structure of the British pig industry (epidemiological denominator) and 2) the spatial and network characteristics of endemic diseases.

Through the combined use of abattoir monitoring and pig movement data, and spatial and network analysis, this project aimed to:

- Identify and characterise the "active" British pig holdings regarding their demographic, spatial and network structure;
- Explore the spatial and network distribution of three endemic conditions: Enzootic Pneumonia, Ascariosis and Sarcoptic Mange;
- Assess the weighted contribution of farm spatial and network characteristics to the prevalence of Enzootic Pneumonia, Ascariosis and Sarcoptic Mange.

Due to time constrains, however, the project only focused in the first objective (Identification and Characterisation of the pig demographic, spatial and network structure). This report will present the project findings for this Objective.

A. Literature Review

Pig Production in Great Britain

The British Pig Industry is one of the largest in the European Union (EU), occupying 9th position in terms of meat production (Eurostat, 2010). According to the last agricultural census, there are 4.7 million pigs on 7,900 pig farms in GB (Defra, 2009a; Defra, 2010a). The British Pig Executive (BPEX) a division of the Agriculture and Horticulture Development Board (AHDB) has estimated that 92% of this population is distributed over only 1,400 commercial farms, the rest being kept on 10,000 small holdings (BPEX, 2010). The distribution of pigs, breeding sows and farms in Great Britain (GB) available in the literature can be observed in Figure1 (Defra, 2009b; Defra, 2006; Scottish Government, 2010; WAG, 2010a; WAG, 2010b).

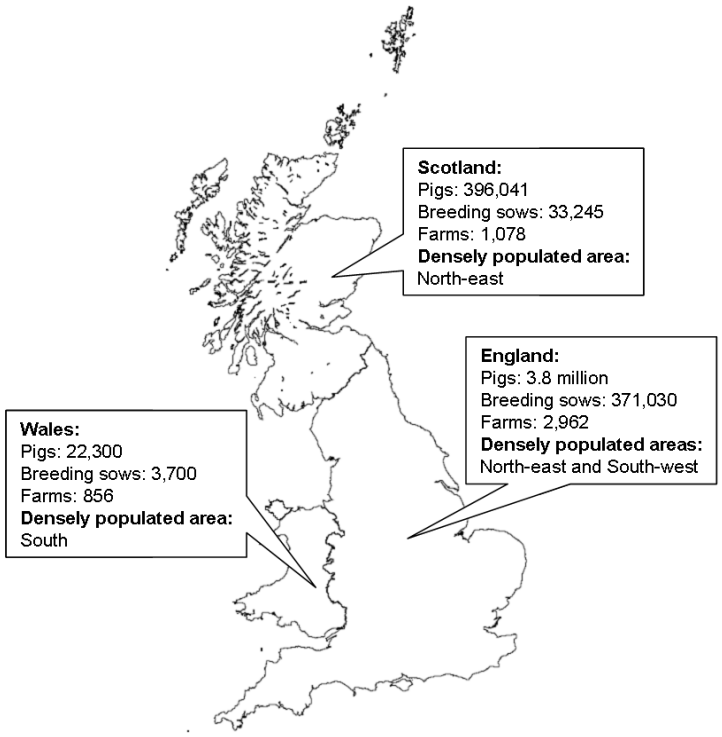

Figure 1 – Distribution of pigs, breeding sows and farms in England, Scotland and Wales.

The information in Figure 1 has been obtained from different sources, at different times and referring to different populations, therefore, a comprehensive “snap shot” of the sectors of the industry is not readily available. This lack of detailed and representative information about the GB pig population, i.e. the “denominator”, is a major knowledge gap for any epidemiological investigation.

The British pig industry is organised in a pyramidal structure. At the top of the pyramid there are a small number of nucleus herds that produce purebred sows/boars and provide animals to multiplier herds. Those represent a larger number of specialised farms that have as their objective the production of crossbred pigs and replacement gilts to supply the commercial farms. The nucleus and multipliers farms are also commonly known as breeding holdings, whereas the commercial farms are known as production holdings. These represent the base of the pyramid and produce pigs to send to slaughter (Defra, 2010b).

These different types of holdings are also likely to be different regarding their biosecurity, pig health status, management and hygiene practices. This pyramidal structure assumes a constant flow of animals within and between different types of holdings and its objective is to optimise feeding and management procedures, to prevent health problems and to be cost-effective. Pig production in GB mainly occurs indoors and the animals are grouped by stage of production or weight/age, i.e. groups of dry sows, lactating sows, gilts, piglets, weaners, growers and finishers. Approximately 30% of pigs are born and raised in outdoor herds but they are usually finished indoors (BPEX, 2010). Any epidemiological study aiming to understand the flow and distribution of disease across farms needs to account for this pyramidal structure. In GB, farm category information is only available for the commercial units through quality assurance programmes. These are voluntary schemes where the holdings are inspected by a veterinarian and an independent inspector (BPEX, 2010; QMS, 2010). According to the information available in the literature, 92% of the pig production (BPEX, 2010) and 2,168 premises (Stark and Nevel, 2009) are registered in assurance schemes. The schemes available within GB are Assured British Pigs, Genesis Quality Assurance and Quality Meat Scotland. Such schemes account for standards on traceability, food safety, animal welfare and pig husbandry that go beyond what is required under UK legislation and are aggregated in a common label name – Red Tractor.

Epidemiological data sources and analysis

Movement records

In order to prevent/control animal health problems and disease transmission between herds, it is useful to have tools that provide efficient animal and holding identification as well as livestock movement recording systems (Madders, 2006; National Audit Office, 2003). Currently, there are two pig movement recording systems: the Animal Movement Licensing System (AMLS) for England and Wales, and the Scottish equivalent – Scottish Livestock Electronic Identification and Traceability (ScotEID) database system. The latter started in November 2011 and its predecessor was the Scottish Animal Movement System (SAMS),

from which the data included in this study came and which is, therefore, the system that has undergone analysis. The main objective of both systems is to record batch movements of pigs, since September 2002 general licences have been issued to allow movements to take place without prior approval, provided that they are reported (National Audit Office, 2003). Pig movements are regulated through the PRIMO – The Pigs Records, Identification and Movement Orders (Anonymous, 1995; Anonymous, 2002; Anonymous, 2007; Anonymous, 2008). The keeper is requested to complete a "movement reporting document" (e.g. AML2 form for England and Wales), that travels together with the animals and contains information regarding the holdings of departure and destination and the animals being transported. All movements need to be reported to the local authority within 3 days of the movement taking place and recorded in the farm movements log book. The data are checked before insertion into the AMLS/SAMS, however, the level and precision of validation performed during data entry is unknown (Upton and Claridge, 2009). The data present in AMLS/SAMS are transferred periodically to a national information management system – RADAR (Rapid Analysis and Detection of Animal-related Risks). The RADAR unit gathers, analyses and disseminates data from several sources, e.g. AMLS/SAMS and United Kingdom (UK) government databases containing livestock, agricultural holdings or animal health data (Defra, 2010c). National animal movement data are merged in RADAR and checked for integrity and validity. This accounts for any differences between sources, e.g.: 1) the data are compared to avoid duplicates of cross-borders movements; 2) the record of movements via markets from SAMS are split into two records as in AMLS[1]; and 3) Scottish premises are categorized as market, slaughterhouse or agricultural holdings because SAMS does not provide the premise type information consistent with AMLS (Holdship, 2009).

Abattoir Monitoring

In GB, two abattoir-monitoring health schemes are in place: the BPEX Pig Health Scheme (BPHS) and Wholesome Pigs Scotland (WPS), both of which are aimed at the investigation of pathologies detected during *post-mortem* inspection of slaughtered pigs. The inspections are carried out in 18 abattoirs (4 in Scotland and 14 in England) by swine specialists trained for this purpose, during scheduled assessment days, the dates of which are communicated to the producers in advance. The WPS aims for 5 days/quarter, whereas BPHS plans 4 days/abattoir/month for assessment purposes, and both schemes aim to assess every producer every quarter. WPS assessment is a requirement of quality assured producers in

[1] SAMS captured movement as a single record (e.g. farm A – market – farm B) which allows to track the animals between farms. AMLS capture the data as 2 separated records without a link between them (farm A – market and market - farm B).

Scotland; therefore 95% of the commercial units are monitored (in 2013, 66 slap marks, 11,278 pigs and 566 batches were assessed). In the BPHS scheme, both members and non-members of the scheme are assessed on the days the veterinary inspectors are in the abattoir, therefore, 75% of the English/Welsh commercial units are being monitored (in 2013, 1442 slap marks, 217,637 pigs and 4884 batches were assessed) (Correia-Gomes, personal communication). This information is held centrally in a database and reports containing the prevalence and overall trends are provided to the producers.

The pathologies investigated in the health schemes relate to welfare problems in the herds or infection by endemic pathogens, usually associated with performance impairment. There are twelve pathologies assessed: enzootic-pneumonia-like (EP-like) lesions, pleural adhesions, pleuropneumonic lesions, viral-like pneumonia, liver milk spots (MS), hepatic scarring, papular dermatitis (PD), tail damage, peritonitis, pericarditis, pyaemia and abscesses. Most of the conditions are scored for the presence/absence of lesions except the EP-like lesions, pleural adhesions and PD, which are recorded according to categories that represent the severity of the lesions.

Network Analysis

The analysis of the network structure of the livestock industry is an important tool for disease control strategies; animal movements and purchasing policies are regarded as important disease risk factors and routes of disease spread (Gibbens et al, 2001; Woolhouse et al, 2005; Fevre et al, 2006).

Network analyses (NA) can be used in veterinary epidemiology to investigate livestock movement between holdings (e.g. farms) and to allow 1) identification of targets for interventions, control procedures and surveillance; 2) study of disease spread through populations using mathematical models and simulations; 3) identification of 'nodes' with high probably of getting infected and transmitting disease through the network (Christley et al, 2005).

The NA parameters commonly applied in veterinary epidemiology can be grouped according to the following main types (Martinez-Lopez et al, 2009a; Dube et al, 2009):

1) the intra-network measures that investigate the individual characteristics of the nodes of a network, e.g. the node degree centrality - the number of contacts a node has (i.e. number of movements a farm has), the ingoing/outgoing infection chain (i.e. number of connected holdings by direct movements and indirect contact through earlier or further movements in the chain) (Noremark, 2010), or the node clustering coefficient (i.e. a measure for the probability that two neighbours of a farm are also direct neighbours themselves)(Watts and Strogatz, 1998);

2) the inter-network measures that study the network attributes and allow inter-network comparisons, e.g. the network size (i.e. number of farms and movements), network clustering coefficient (i.e. the level to which farms in a network tend to cluster together) (Newman, 2003) or detection of network communities, e.g. ”Q’ algorithm” (i.e. detection of a subset of a network of farms with a larger quantity of movements between each other than external movements) (Fortunato, 2010; Kao et al, 2007; Newman, 2004).

The animal movement records have been explored with NA to characterise and study the contacts between livestock holdings. Livestock industry characteristics of several countries have been described through this methodology (Christley et al, 2005; Green et al, 2008; Natale et al, 2009; Webb, 2006; Dent et al, 2008, Green et al, 2009; Ribbens et al, 2009). These characterizations allowed a better understanding of the behaviour of animal movements within the industries network, providing the basis for further work on disease investigations and surveillance.

Spatial analysis (SA)

Spatially variable factors are known to play a role in the survival and spread of livestock pathogens, which might be responsible for their heterogeneous distribution in space. The spatial variation is mainly attributed to: macro-scale (or first-order) effects that are responsible for the differences of distant geographical regions (e.g. difference in temperature from north to south of GB); and the micro-scale (or second-order) effects that are responsible for the local dependence of a spatial process (e.g. local conditions allowing the survival of a disease vector). On this basis, measurements obtained at proximate locations tend to be more similar than those which are taken further apart (Diggle, 2003).

Accounting for the spatial dimension while investigating animal diseases may provide additional insight into spatial risk factors and the identification and visualisation of disease patterns.

Spatial patterns of disease can be categorised as regular, random or clustered (Pfeiffer et al, 2008). The clustering of a disease can occur for a variety of reasons, such as the infectious spread of a disease, local risk factors or occurrence of disease vectors in specific locations. This type of pattern can be detected using spatial clustering techniques that account for the distribution of the population at risk and the spatial dependence due to geographical proximity, as well as testing for statistical significance of the cluster. One example is the Spatial Scan Statistic (Kulldorff, 1997) method where circular windows imposed on the map “scan” the data for areas of elevated (or reduced) disease frequency.

Combined spatial and network analysis

SA and NA applied independently to investigate mechanisms or the risk of disease spreading may underestimate important aspects of disease transmission between farms. For example, to classify a farm with low-risk of disease based on the low farm-density of the geographical area can be misleading if the farm has a high frequency of contacts (animal movements) with other distant farms. Conversely, considering only the commercial relationships between farms whilst overlooking geographical distances might underestimate the risk associated with local spread of disease e.g. air-borne disease spread.

The integrated application of both methodologies has been reported in the literature (Faust et al., 1999; Gilbert et al., 2005; Martinez-Lopez et al., 2009b).

B. Datasets

Data cleansing and comparison process

In order to have a better grasp of data potential and limitations, a cleansing and comparison process was applied to the pig movement data prior to the data analysis. This step provided in-depth information useful for understanding the data and to take into account in future analysis.

Datasets available

The GB pig movement data were obtained from RADAR in December 2009 (version 1 – movements 2006-2009) and in March 2012 (version 2 – movements 2006-2011). The records provided by RADAR were submitted to a cleaning process and explored for both illogical and inconsistent information. This process consisted of: a) Correction of inconsistencies in the holding type; b) Renaming of “Unknown”, “Non-AMLS” and “Common Land” CPHs as “Farm”; c) Removal of “AI Centre”, “Port”, “Research Centre” and “Veterinary” holding types; d) Removal of movements with the same CPH number in departure and destination CPH field; e) Removal of “illogical” or irrelevant movements such as Abattoir-to-Farm or Market and Abattoir-to-Abattoir. CPH is the County, Parish, Holding number, this is a series of numbers used to identify a specific location (farm, abattoir, market, etc.).

The inconsistencies on the holding type were analysed between datasets, i.e. between version 1 and version 2, and the less generic designation was kept – e.g. “Farm” was kept over “Unknown”. The corrected version was also analysed for inconsistencies within dataset and the same principle was applied. The “Unknown” and “Non-AMLS” holding type are likely to be temporary CPHs or CPHs for which information about the holding type is not held within RADAR. Together with “Common Land” these were renamed as “Farm”. The renaming and exclusion of other holding types was applied for simplicity of future analysis whilst capturing the majority of pig movements and those that were most relevant. The geographical coordinates of holdings were also explored in order to detect illogical values and inconsistencies, such as several coordinates per CPH or coordinates outside GB or over water.

A data comparison process was applied with the objective to compare the records held by RADAR with other sources of animal movement records. According to legislation from 2006-2011, all pig movements need to be reported in paper format and this information is recorded and kept by the departure holding, destination holding and local authorities. Keeping the

same information at different locations provides an opportunity to check the quality of the data, i.e. verify if the same information was recorded in both datasets, and check its accuracy in terms of the number of pigs reported. In this study, the RADAR dataset (i.e. the movement information that is sent to the local authorities) was checked against two private producers' datasets (i.e. movement information kept by the producers) and against abattoir monitoring schemes dataset (i.e. proxy of data kept by abattoirs – pig consignments received for slaughter (Sanchez-Vazquez et al., 2011)).

The datasets used in the comparison were: a) RADAR dataset (government-held pig movement records, combined movements from AMLS and SAMS, subset of movements from years 2006-2009); b) Sprod and Eprod datasets (pig movement records from one Scottish and one English pig producer, respectively); and c) BPHS and WPS datasets (abattoir monitoring data - number of pigs submitted for slaughter as recorded in the "kill-sheets" and number of pigs assessed during assessment days, for England/Wales and Scotland, respectively). The dataset fields, number of records and time period represented on each dataset are described in Table 1.

For the comparison of the movements "farm-abattoir" from RADAR, three datasets were used: BPHS, WPS and Sprod – which were merged into – "Abattoir" dataset. RADAR captures the animal movements from farm to abattoir, the date of departure from farm and uses CPH numbers to identify both holdings; the BPHS/WPS datasets hold information about the animals present in an abattoir on the assessment day[2], use the herdmark to identify the farm of origin and use the postcode to identify the abattoir. The number of records comparable between RADAR and BPHS/WPS datasets was limited, i.e. only the records for which the farm herdmark was available[3] and where it was possible to identify the abattoir CPH (through association between abattoir postcode and coordinates in RADAR). The comparison was made using those records for which the assessment date was equal to departure date as well as those for which the assessment date was the day following the departure date. The records from Sprod and Eprod datasets regarding "farm-to-farm" and "farm-to-market" movements were merged into "Farms" and "Market" datasets, respectively. The records present in Sprod and Eprod datasets allowed the comparison to be made through a direct link between the CPH numbers and dates of departure from farms. Similarly to the comparison above, this comparison was limited by the dates of movements and number of holdings available in the datasets.

2 The assessment date could be different from departure from farm date because it refers to the day the animals are slaughtered. This date could be the day following departure from farm due to the travelling time, the arrival of animals after slaughtering had stopped, or slaughterhouse policy of "resting" animals between transport and slaughter.

3 Farms with more than one herdmark per CPH (10-mile and same ownership) or more than one CPH per herdmark (e.g. error) were removed to avoid duplicating records when matching in both datasets.

The main objectives of the comparison process were to quantify: 1) the number of comparable movements between datasets – same departure and destination holding and date of movement; 2) the agreement between the numbers of animals reported; 3) the number of non-comparable records.

Table 1 – Description of datasets available (dataset fields, time period and number of records).

Dataset	Dataset Fields	Time	No. Records	No. Movements	No. Animals
RADAR	Departure and destination CPH number Departure and destination holding type (abattoir, farm, gathering, other[4]) Departure and destination holding coordinates[5] Date of departure from departure holding Number of movements per record[6] Number of animals per record[6]	01/01/2006 to 30/11/2009	735,754	788,326	54,183,009
Sprod	Departure and destination CPH number Departure and destination Herdmark number Departure and destination holding type (abattoir, farm or gathering) Date of departure from departure holding Pig categories Number of animals transported Number of animals dead in transit Haulier name	One week per month in year 2008[7]	1,349	1,349	186,191
Eprod	Departure and destination CPH number Date of departure from departure holding Number of animals transported	Year 2008	108	108	29,245
BPHS	Date of assessment Herdmark number from farm of origin Abattoir name and postcode	Years 2006-2009	1,492 (members and non-members)	16,784	2,101,081 (submitted) 718,600 (assessed)
WPS	Number of animals submitted for the assessment Number of animals assessed Individual results on the lesions from post-mortem inspection	Years 2006-2009	271 (members)	1,275	132,854 (submitted) 61,406 (assessed)

The above mentioned analyses were executed using the following software: SAS 9.2 and R 2.12.2.The movement data was obtained from RADAR; the producer's datasets were obtained directly from the producers; the BPHS data was obtained from BPEX and WPS data from Quality Meat Scotland (QMS).

[4] Other (Artificial Insemination centre; Common Land; "Non-AMLS" – no CPH records in RADAR; Port – Airport or Seaport; Research centre; Unknown CPH – CPH without location type description; RADARNI1/RADARNI2 CPH – name give to the CPH numbers for ports Stranraer and Cairnryan; Veterinary holding).

[5] Projected coordinates according to British National Grid – Northing/Easting.

[6] E.g. 2 vehicles carrying pigs from CPH A to CPH B in same day are present in dataset as 1 record, corresponding to 2 movements and the number of pigs reported is the sum of the 2 movements.

[7] In this company there is a weekly pattern of moving certain pig types on specific days of the week (i.e. weaners gilt replacement usually take place on Thursdays). For this reason, a whole week period for each month of the year 2008 was recruited.

Data cleansing process

The data handling and data cleaning steps provided not only a better understanding of the animal movement data but also helped to identify possible limitations for epidemiological analyses. Inconsistencies were found in the holding type between the versions of the datasets for 1,649 CPHs and within the corrected dataset for 102 CPHs. In the absence of a "validation dataset", the principle of selecting the less generic designation was applied. This solution is not ideal and brings attention to potential caveats in holding type designation. The difference between location types in datasets obtained at two different points in time might be caused by updates on holding type designation over time. Misclassifications are also likely to happen due to differences between Scottish and English/Welsh recording systems. Renaming Unknown, Non-AMLS and Common Land under the general description "Farm" might overestimate the pig producers in GB but will assure that the majority of relevant movements are captured in the dataset. The other holding types were removed due to the small role their movements play in the pig industry. The movements with the same CPH number in departure and destination were removed – these could be movements to premises without CPH (e.g. fair) and return to original CPH. Illogical or irrelevant movements such as movements from Abattoir to Farm or Market and movements Abattoir to Abattoir were also removed (there were only 1,881 movements being the majority between Abattoirs).
The full RADAR dataset comprised a total of 1,249,712 movements recorded over 6 years (2006-2011), corresponding to 84,191,473 pigs transported between 57,845 different CPH codes. After the cleaning process, there were a total of 1,240,400 movements corresponding to 83,428,569 pigs transported between 57,771 CPH codes (see Tables 2-4).

After the data cleaning, the movement records were submitted to the comparison process where comparison of only a subset of the RADAR movement data was used – years 2006 to 2009. The comparisons were made for the following movement types: farm-to-abattoir, farm-to-farm and farm-to-market.

During this exercise, systematic errors were identified and reasons for non-matching and non-agreement were found, e.g. the comparison of different dates, the problem of aggregated data and data entry errors. Non-matching may also be explained by limitations in data representativeness. These limitations include: 1) the time-frame available for comparison, i.e. the BPHS/WPS dataset only contain data for the days the assessments occurred and the producer dataset only contained a sample of movements occurring in year 2008; 2) the holding representativeness available, i.e. the abattoir schemes operate only in specific abattoirs and neither the abattoir nor the producer datasets are representative of the

totality of the GB pig producers, nor the totality of GB pig movements; 3) the type of holding identifier available, i.e. BPHS/WPS datasets use herdmark and postcode instead of CPH as farm and abattoir identifier, respectively - therefore the inclusion depended on the availability of the herdmark-CPH link for farms and postcode-geographical coordinates-CPH link for abattoirs.

Considering the datasets with the systematic errors removed (in abattoir and farms comparison), the main results were:
1) The number of comparable records was 7,724 (1% of all RADAR movements).
2) There was agreement in the number of animals reported in 5,605 movements (73%), the overall mean difference obtained was -0.16 (95% CI [-52, 52]) and 96% of the non-agreement records have differences less than 52 animals.
3) In total, only 74 movements were found to be absent from the RADAR dataset provided.

This comparison highlighted that the majority of the comparable movements show an agreement in the numbers reported and that only a small amount of movements were identified as underreported in RADAR dataset. Therefore, the RADAR dataset is considered a useful source for analysing the pig movements in GB.

RADAR dataset limitations

Holding identifier

According to legislation, a pig keeper needs to register the building/area where the pigs are kept. After the registration, a herdmark (alphanumeric code) is issued for each pig herd (Anonymous, 1995; Anonymous, 2002; Anonymous, 2007; Anonymous, 2008) together with a building/area identifier - CPH number (county/parish/holding number). The simplest scenario is a pig farm having one CPH number allocated, which would correspond to one herdmark. In reality, however, there are CPH numbers that contain several herdmarks and farm sites that, due to their size, contain several CPH numbers. The rule in place requires that there should be one CPH code for the land within 10 miles radius of farm office (DEFRA, 2010d). The same identifier can also have several interpretations – keeper identifier, a group of land parcels or just a reference when reporting movements (Vince and Wild, 2008). Furthermore, the single point in space provided may not be the accurate representation of the location where the animals are kept – it could be a pig farm or an administrative office (NAO, 2003; Madders, 2006). The advantages and the drawbacks of the CPH number as an identifier have been assessed by several authors and recommendations have been made for

improvement; nonetheless, this system that originated in GB in the 1940s is still in use nowadays (Madders, 2006; Vince and Wild, 2008; DEFRA, 2010d).

During the cleaning process, no inconsistencies were found in the format of CPH codes provided by RADAR and it was not possible to validate the link between a specific holding and its CPH code. However, data limitations such as the potential for error in the data entry process by the local authorities were identified. Although unlikely (due to quality procedures implemented by local authorities), this data entry error could result in unreal CPHs (i.e. not corresponding to a pig farm); this could, in turn, result in overestimation of the total number of pig farms in GB. Another limitation found is the fact that a CPH may correspond to more than one herdmark. As a result of the comparison process, it was possible to observe that, when comparing datasets with different holding identifiers (e.g. BPHS/WPS datasets use herdmark instead of CPH as farm identifier), it may be impossible to match records if the CPH-herdmark link is inexistent or insufficient (i.e. only one CPH identifier for several herdmark identifiers).

After the cleaning process all the CPHs remaining were considered accurate; however due to the high number and discrepancies with numbers reported by census or industry, it is believe that a further CPH categorisation will be useful for further analysis to differentiate between types of producers/pig holdings.

Holding Coordinates

The geographical location of agricultural premises is fundamental when studying the spatial distribution of a livestock population. A single geo-referenced point, such as farm main building, was identified as a meaningful central point for the farm (Durr and Froggatt, 2002) and should, to some extent, represent the location of the animals in the farm. The quality of the geo-referencing depends upon the quality and detail of the source data and on the success of the address matching process (Paiba et al., 2007).

Internally, RADAR consider two types of coordinates: the “source coordinates”, i.e. location coordinates that are provided from the source data, and the “best coordinates”, i.e. location coordinates that are inferred from an address matching process (Upton and Claridge, 2009). After the RADAR internal validation procedures, the most accurate coordinates for each CPH are provided. It was out of the scope of this study to validate each holding location, but the data were explored in order to try to detect illogical values and inconsistencies between the records provided.

The potential limitations of the location data available are: 1) the absence of location data limits the description of events or any spatial inference - only very few holdings did not have coordinates available (eight farms); 2) the occurrence of inaccurate location data might influence the results of analysis depending on the accuracy of the geo-referencing process

and whether there was bias present, e.g. towards a specific type of premise or a specific region – the only illogical result found was the existence of nine farms over water, however, it was out of the scope of this project to validate the accuracy of each geographical location in representing where the pigs are being kept; 3) whenever several CPHs share the same coordinates, it will be impossible to analyse spatial differences between these premises – only 3.5% of CPH had shared coordinates.

Despite the potential for small inaccuracies in the geographical location of pig holdings, it is believe that the majority of the locations provided are useful and reasonably accurate for epidemiological analysis.

Holding location type

The location type field is attributed by RADAR to each premise CPH in order to differentiate farms, slaughterhouses or markets. The consistency of the records was checked between and within datasets in the cleaning process. The inconsistencies found may be a consequence of data updates (e.g. CPH location type updated over time) or errors matching several sources of data (e.g. matching CPH code and CPH location type). Due to the small number of inconsistencies found, the last explanation is less likely to be the case. The inconsistent records were compared, a selection process was applied (i.e. the most informative classification was kept) and the designation was "corrected" where possible. In the absence of a validation dataset, this was the only solution found, and whilst not ideal, it brought to attention potential drawbacks in the data supply from RADAR. Inconsistencies within the same dataset, i.e. a CPH with more than one location type, may be caused by differences between recording systems (AMLS-SAMS) which were easily corrected. Renaming of "less specific" location types to farm aimed to include the maximum possible number of CPHs and consequently to cover the majority of pig movements occurring in GB. A possible drawback might be an overestimation of pig producers in GB.

There are three types of information provided by RADAR regarding the movement record: 1) the date when the movement occurred; 2) the number of movements per record; and 3) the number of pigs transported.

Date of movement

The movement date provided was the date of departure from the holding of origin, since the movements are expected to occur within less than 24h. No inconsistencies were found in the dates provided, and if the date/time of departure and arrival was provided, it would allow the calculation of travelling times.

Number of movements per record

Several movements may be aggregated in one record if pigs were transported from the same origin to same destination in the same day. No inconsistencies or illogical values were found; however, the aggregation of movements has proven to be a drawback when comparing records from RADAR with other data sources. This problem was identified as a possible reason for the non-agreement in the number of pigs reported between datasets and an improvement of results was observed when data was manipulated to account for the data aggregation caveat.

Number of pigs transported

The accuracy in the number of pigs transported was assessed when comparing RADAR dataset with datasets from other sources. The agreement between datasets for movement types was: 70% for farm-to-abattoir, 95% for farm-to-farm and 99% for farm-to-market. On the whole, the agreement was very good and RADAR was very accurate regarding the number of pigs that were being transported in GB.

During this exercise, potential reasons for the non-agreement in number of pigs reported between datasets were found: 1) pig death during travelling; 2) inaccuracy of the number reported, e.g. digit preference bias or data entry error; or 3) difficulties of comparing datasets from different sources. It may be related to the existence of a systematic error in the record matching (record matching over different dates, i.e. difference between the BPHS/WPS assessment date and the movement date of departure from farm), or a record being correctly matched but having aggregated values (the value does not represent the pigs assessed by BPHS/WPS at abattoir, i.e. several movements aggregated in one record in RADAR and only a fraction were assessed). The data manipulation applied improved the agreement observed, supporting the hypothesis that the non-agreement may be partially explained by the problems found when comparing two different datasets.

Under-reported movements

According to the legislation all pig movements between holdings should be reported through a movement reporting document, but the potential under-reporting of movements cannot be disregarded. This might be a source of bias if representative of a large proportion of movements or a specific type of movements. Under-reporting can comprise an illegal movement not being reported or a movement reported but corrupted after being submitted to local authorities, i.e. record lost or affected by data entry errors.

The biases and limitations have been investigated for CTS data (NAO, 2003; Mitchell et al., 2005; Robinson and Christley, 2006; Green and Kao, 2007; Vernon et al., 2010). In our study, due to the limitation in representativeness of the datasets available, it was not possible

to assess if there was any bias towards specific type of movements or movements towards specific types of premises. According to RADAR, however, illegal movements are not a common situation and it is believed that the majority of movements are reported (Upton and Claridge, 2009). Such a statement also agrees with the results of the comparison process, which found that the quantity of under-reported movements in RADAR was very small (0.95% of comparable records).

Another possible source of under-reporting was the within-business movements not being captured by RADAR, i.e. movements between holdings in a 10 mile radius belonging to the same CPH and ownership. However, when comparing RADAR against the private producers' datasets it was possible to observe that the majority of movements were reported.

Illogical and irrelevant movements

Certain types of illogical movements appeared in the data, such as abattoir-to-abattoir and abattoir-to-farm. These are illegal according to legislation and were removed since they are believed to have negligible impact in the future analysis. These could be either an incorrect classification of the location type or an illegal movement being recorded. Also, movements between same CPH were removed due lack of usefulness when studying contacts between different CPHs.

Simple drawbacks

Other simple drawbacks of the data were found, such as useful information that is not being recorded or is not being imported to the RADAR database. Examples of this include: 1) the type of pig being transported (i.e. differentiation between piglets/weaners/finishers/sows/ boars) or reason for movement, which would help with farm/holding characterisation; 2) the haulier movement routes, the time of travel and details about multiple pick-ups/drop-offs, which would allow the calculation of path distance; 3) the herdmark number, which would allow farm differentiation should a CPH have several associated herdmarks; 4) the link between farms when batches are moved via market, which is recorded in Scotland but rearranged and lost in order to be compatible with England/Wales records; 5) the details about farm types/production site details. These issues may only limit the detail provided in the results but not introduce bias.

C. Pig industry characterisation using GB movement data from 2006 to 2011

During the literature review it was noticed that a comprehensive description of the different sectors of the British pig industry was not available. Obtaining information about the British pig population, i.e. the epidemiological denominator, is believed to be useful for further epidemiological analysis. With the electronic records of pig movements, an opportunity emerged to identify and characterize the "active" pig holdings regarding:

- farm type (i.e. breeder, breeder-finisher, and finisher);
- farm, gathering (e.g. market) and abattoir size, location and geographical density;
- number of movements and pigs moved between farms, farms and gatherings or from farms to an abattoir;
- number of different sources and destinations of pigs;
- distance travelled and the temporal variation of movements between different types of holdings.

The pig movement data was used to characterise the pig holdings and to study the occurrence of patterns of links between the different types and sizes of holdings, different regions and different time periods. This type of industry characterisation can have several applications, such as: disease control (e.g. study of the pathogen occurrence and spread between holdings); animal welfare (e.g. study of the impact of distances travelled on animal welfare); or commercial operations (e.g. study of the effect of temporal patterns of movement on animal trade).

C.1 Descriptive analysis

The data available (from 2006 to 2011, GB-wide) was explored to provide insight into the geographical aspects of the pig movements in GB. Each record consisted of a departure and destination holding (identified by its CPH code), a movement date, geographical location of the holding[8], number of movements and number of pigs moved. The main methods and objectives were: 1) provide a general overview of the pig industry in GB in terms of the number of holdings, movements and pigs moved over the different years; 2) explore the spatial distribution of pig farms in GB through the number of farms per region, the count of farms within a 3km radius[9] and the farm density in a region[10]; 3) assess the proportions of different types of movements and the distances travelled for the whole of GB, within GB countries and between GB countries[11]; 4) explore holding characteristics representative of

[8] Using the holding coordinates, each CPH was allocated to its GB NUTS II location (Nomenclature of Units for Territorial Statistics).

[9] The choice of this distance was based in the value suggested for aerosol transmission of *Mycoplasma hyopneumoniae* (Desrosiers, 2001).

[10] The region farm density was expressed in number of farms by 100 square kilometres.

[11] The distance was calculated using Pythagoras Theorem (Euclidean distance) and expressed in Km travelled.

production intensity and between-holding connectivity (number of movements and pigs moved, batch size and in/out degree – i.e. number of sources. There were some discrepancies in total number of movements and total number of pigs being moved presented in the tables below because it was not possible to attribute a region to all CPHs (explained in more detail below). For clarification, several pigs can be moved in one pig movement.

The above mentioned analyses were executed using the following software: SAS 9.2; R 2.12.2; ArcGIS 9.3; and Hawth's Analysis Tools v3.27 package for ArcGIS. The NUTS II geographical data was obtained from EDINA website (UKBORDERS).

General data overview

The pig industry in GB differs between regions and in order to give better insight, a descriptive summary of the main movement figures are showed below.

The number of holdings included in the movement database varied over the years – the number of farms varied from 18,358 to 27,143, the number of abattoirs varied from 203 to 241, and the number of markets varied from 171 to 248. In total, the farm CPH accounted for 98.6% of all CPHs in the movement dataset (Table 2).

Table 2 – CPH overview – total number and percentage of CPHs per year in GB

	Number of CPH (%)			
Year	Abattoir CPH	Farm CPH	Market CPH	Total
2006	241 (1.3)	18,358 (97.5)	223 (1.2)	18,822
2007	234 (1.2)	19,637 (98.0)	171 (0.8)	20,042
2008	213 (1.0)	21,455 (98)	219 (1.0)	21,887
2009	211 (0.8)	24,440 (98.2)	248 (1.0)	24,899
2010	203 (0.7)	27,779 (98.5)	220 (0.8)	28,202
2011	220 (0.8)	27,143 (98.3)	236 (0.9)	27,599
Whole period	326 (0.6)	56,976 (98.6)	469 (0.8)	57,771

When looking at pig movements over the years, 70% of the movements were towards abattoirs, 23% towards farms and only 7% destined to market. There was an average of 200,000 pig movements per year (Table 3).

When exploring the movements in and out of farms, it was observed that the majority of farms had movements both inwards and outwards (33,907 – 60%), whereas approximately 21% (12,130) had no inward movements and 19% (10,931) had no outward movements. All market CPHs had both movements in and out, and abattoir CPHs had only inward movements.

Regarding the number of pigs moved, 59% of the pigs were sent to abattoir, 40% to farms and 1% to markets. On average, there were approximately 5 million pigs moved towards farms, 8 million towards abattoirs and only 160,000 towards markets, resulting in a total of around 14 million pigs moved per year in GB (Table 4).

Table 3 – Overview of the movements per year in GB.

	Number of Movements			
Year	Movements to Farm	Movements to Abattoir	Movements to Market	Total
2006	47,560	143,649	13,907	205,116
2007	43,970	144,922	11,176	200,068
2008	44,576	147,897	13,469	205,942
2009	48,825	140,580	14,565	203,970
2010	53,360	146,879	16,950	217,189
2011	46,392	147,066	14,657	208,115
Whole Period	284,683	870,993	84,724	1,240,400
	23%	70%	7%	100%

Table 4 – Overview of number of pigs moved per year in GB.

	Number of pigs moved			
Year	Movements to Farm	Movements to Abattoir	Movements to Market	Total
2006	5,772,461	8,394,800	168,270	14,335,531
2007	5,738,523	8,488,349	132,575	14,359,447
2008	5,531,605	8,276,122	153,983	13,961,710
2009	5,453,339	7,573,916	166,166	13,193,421
2010	5,828,171	7,896,211	192,296	13,916,678
2011	5,306,366	8,191,175	164,241	13,661,782
Whole Period	33,630,465	48,820,573	977,531	83,428,569
	40%	59%	1%	100%

A geographical location was attributed to each CPH. From 56,976 farms, 56,959 have a logical geographical location and are represented in the following analysis. The 17 CPHs excluded included eight farms for which no location was available and nine farms that were geo-referenced over water. The majority of pig farms, 82%, are located in England; Wales account for 10% and Scotland for 8%.

The farm distribution over the different GB NUTS II regions was explored in three ways: 1) the count of farm per region; 2) the farm density per region; and 3) the number of farms in a 3km radius.

The number of farms in a 3km radius was calculated for each farm in each NUTS II region. In GB, 27% of farms had less than five other farms within a 3km radius; 43% of farms had between five to 10; and 30% of farms had more than 10 surrounding farms. When grouping

farms per country, similar proportions were found for England and Wales, however, the majority of farms in Scotland (84%) had between one to five farms in the vicinity (Table 5). The NUTS II regions with higher farm density also contained the farms having a larger maximum number of neighbouring farms within a 3km radius, e.g. 40 farms within a 3km radius in Cornwall and Isles of Scilly, 32 in West Wales and The Valleys and 31 in Highlands and Islands (Table 6).

Table 5 – Number of pig farms in a 3km radius (2006-2011 data).

	Number of farms in a 3km radius							
	1 - 5	%	5 - 10	%	>10	%	Total	%
GB	15,342	27	24,538	43	17,079	30	56,959	100
England	10,129	22	20,874	44	15,957	34	46960	100
Scotland	3,442	84	609	15	37	1	4088	100
Wales	1,771	30	3,055	52	1,085	18	5911	100

The regions with a higher number of farms were East Anglia (England – 4,354 farms) and West Wales and The Valleys (Wales – 4,006 farms). The Scottish region with a higher number of farms was Highland and Islands (1,329) (Table 6 and Figure 2). The farm density per NUTS II region was calculated dividing the number of farms by the region area and expressed as number of farms per 100 km^2. England had the higher density of farms per region, e.g. Cornwall and Isles of Scilly (30 farms/100 km^2) and Dorset and Somerset (24 farms/100 km^2). While in Wales, West Wales and The Valleys region (11 farms/100 km^2), and in Scotland the northeast of the country (five farms/100 km^2) were the regions with highest density of farms (Table 6 and Figure 3).

The pig movement distances in GB were calculated and expressed for each type of movement in different geographical scales 1) whole GB movements; 2) within-country movements; and 3) between country movements (Table 7).

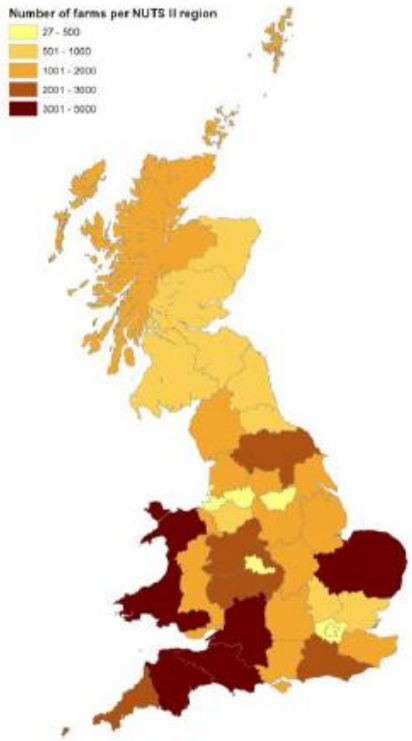

Figure 2 – Distribution of pig farms by GB NUTS II regions – number of farms/region (2006-2011 data).

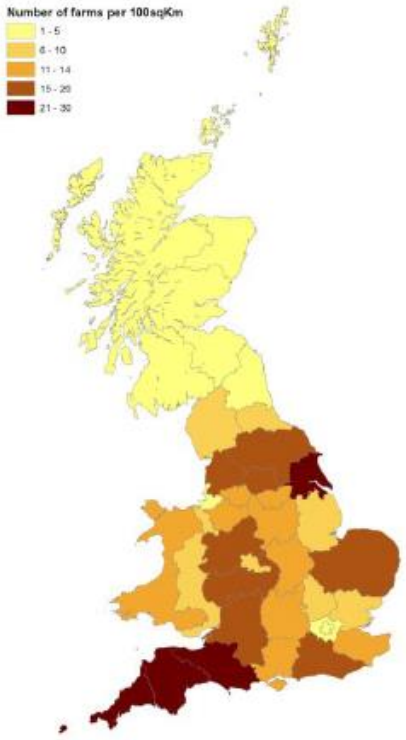

Figure 3 – Pig farm density per GB NUTS II region – number of farms/100 km^2 (2006-2011 data).

Table 6 – Region area, total number of farms, farm density and number of farms in a 3km radius (2006-2011 data).

Country	NUTS II region	Total no. of farms[a]	Area[b]	Farm density[c]	Maximum no. farms 3km radius[d]
England	East Anglia	4,354	12,750	15	28
	Dorset and Somerset	3,502	6,211	24	37
	Devon	3,486	6,841	21	25
	Gloucestershire, Wiltshire and North Somerset	3,094	7,704	17	8
	North Yorkshire	2,756	8,325	15	18
	Cornwall and Isles of Scilly	2,707	3,721	30	40
	Shropshire and Staffordshire	2,624	6,204	17	12
	Herefordshire, Worcestershire and Warwickshire	2,575	5,898	18	16
	Surrey, East and West Sussex	2,429	5,511	18	10
	Derbyshire and Nottinghamshire	1,744	4,790	14	21
	East Riding and North Lincolnshire	1,738	3,658	23	33
	Berkshire, Buckinghamshire and Oxfordshire	1,649	5,743	11	15
	Leicestershire, Rutland and Northamptonshire	1,491	4,918	12	4
	Hampshire and Isle of Wight	1,351	4,251	12	27
	Kent	1,346	3,908	14	23
	Lancashire	1,321	3,264	16	16
	Lincolnshire	1,290	6,107	9	22
	Cumbria	1,286	7,182	7	16
	West Yorkshire	1,039	2,029	20	8
	Essex	930	3,947	9	20
	Cheshire	833	2,380	14	22
	Tees Valley and Durham	766	3,047	10	9
	Bedfordshire and Hertfordshire	737	2,878	10	16
	Northumberland and Tyne and Wear	524	5,630	4	20
	South Yorkshire	490	1,552	13	27
	Greater Manchester	448	1,276	13	12
	West Midlands	170	902	6	24
	Outer London	139	1,267	3	15
	Merseyside	114	816	5	24
	Inner London	27	328	3	23
Scotland	Highlands and Islands	1,329	39,584	1	31
	North Eastern Scotland	971	7,334	5	20
	Eastern Scotland	959	17,989	2	19
	South Western Scotland	828	13,064	2	15
Wales	West Wales and The Valleys	4,006	13,442	11	32
	East Wales	1,905	7,783	10	22

Legend: a Total number of farms reporting movements per year; b NUTS II area in 100Km2; c Farm density – total number of farms/100km2; d Maximum number of farms within 3km radius of each farm in the region; no. – number.

From the total of 1,161,406 pig movements occurring in GB the departure and destination of 56% were in the same region and 97% in the same country. Movements between regions were largely observed when pigs were moved from a market to an abattoir (WHR = 27%), whereas the opposite happened when pigs were moved between markets, i.e. they tend to happened within the same region. The maximum distances travelled were observed in movements between farms (792km) and from farm to abattoir (767km). The median distance of pig movements was approximately 31km for the majority of movement types, except for movements market-to-abattoir (median=53km) and market-to-market (median=71km) (Table 7). Only 14% of the movements involved distances of over 100 km.

Table 7 – Distances and proportion of within-region (WHR) and within-country (WHC) movements in GB (2006-2011 data).

	Movements			Distance			
	Type	**N**	**%**	**Median**	**Max**	**WHR (%)**	**WHC (%)**
GB	**Overall**	**1,161,406**	**100**	**31**	**792**	**56**	**97**
	Farm – Farm	236,175	20.3	26	792	65	97
	Farm – Abattoir	803,325	69.2	33	767	54	97
	Farm – Market	81,139	7.0	27	519	56	96
	Market – Abattoir	12,220	1.1	53	715	27	96
	Market – Farm	28,475	2.5	34	499	50	95
	Market – Market	72	0.01	71	204	81	99

Within-country and between-country movement distances were calculated individually for England, Scotland and Wales (Table 8). The large majority of within-country pig movements occurred in England (91%) with a median of 30km and a maximum of 563km travelled. There was little variation in median distance travelled between different types of movements. In Scotland (6% of movements), the overall median distance travelled was larger – 54km – as well as the median distance travelled from farm to abattoir – 110km. In Wales, the travelled distances were smaller (median=19km) and approximately 87% of movements occurred within the same region; also, no movements between markets were observed.

The movements between countries accounted for only 3% of the total pig movements and the higher values observed for median and maximum distance travelled were 85km and 792km, respectively. The majority of movements occurred from Wales to England (38%), Scotland to England (34%) and England to Wales (24%). Only a small fraction of movements occurred from England to Scotland and between Scotland and Wales. The largest distances were observed in movements between Scotland and England (Table 9).

Table 8 – Within-country movement distances, and proportion of within-region movements (2006-2011 data).

	Movements			Distance		
	Type	**N**	**%**	**Median**	**Max**	**WHR (%)**
All within-country movements	**Overall**	**1,129,984**	**97.3**	**30**	**563**	**57**
	Farm – Farm	229,835	20.3	25	563	67
	Farm – Abattoir	783,159	69.3	33	537	55
	Farm – Market	78,177	6.9	26	486	58
	Market – Abattoir	11,785	1.0	53	441	28
	Market – Farm	26,957	2.4	32	499	52
	Market - Market	71	0.01	70	183	82
England	**Overall**	**1,025,648**	**90.8**	**30**	**563**	**56**
	Farm – Farm	196,920	19.2	25	563	65
	Farm – Abattoir	722,162	70.4	32	536	55
	Farm – Market	70,854	6.9	26	486	56
	Market – Abattoir	11,683	1.1	53	441	28
	Market – Farm	24,006	2.3	33	499	48
	Market-Market	23	<0.1	67	183	48
Scotland	**Overall**	**62,572**	**5.5**	**54**	**410**	**59**
	Farm – Farm	24,049	38.4	35	410	75
	Farm – Abattoir	33,525	53.6	110	396	45
	Farm – Market	4,343	6.9	25	400	78
	Market – Abattoir	75	0.1	36	68	100
	Market – Farm	532	0.9	36	312	85
	Market-Market	48	<0.1	71	88	98
Wales	**Overall**	**41,764**	**3.7**	**19**	**217**	**87**
	Farm – Farm	8,866	21.2	13	214	86
	Farm – Abattoir	27,472	65.8	19	217	87
	Farm – Market	2,980	7.1	23	207	83
	Market – Abattoir	27	0.1	26	153	70
	Market – Farm	2,419	5.8	28	207	85

Note: WHR – Within region movement

Table 9 – Between-country movement distances (2006-2011 data).

	Movements			Distance	
	Type	**N**	**%**	**Median**	**Max**
All between-country movements	**Overall**	**31,422**	2.7	**85**	**792**
	Farm – Farm	6,340	20.2	123	792
	Farm – Abattoir	20,166	64.2	84	767
	Farm – Market	2,962	9.4	65	519
	Market – Abattoir	435	1.4	404	715
	Market – Farm	1,518	4.8	70	493
	Market - Market	1	0.0	204	204
England – Scotland	**Overall**	**774**	2.5	**93**	**792**
	Farm – Farm	363	46.9	279	792
	Farm – Abattoir	396	51.2	43	722
	Farm – Market	1	0.1	356	356
	Market – Farm	14	1.8	229	483
England – Wales	**Overall**	**7,715**	24.6	**38**	**376**
	Farm – Farm	2,059	26.7	66	376
	Farm – Abattoir	4,069	52.7	29	340
	Farm – Market	153	2.0	65	258
	Market – Abattoir	68	0.9	76	154
	Market – Farm	1,366	17.7	70	331
Scotland – England	**Overall**	**10,847**	34.5	**306**	**783**
	Farm – Farm	1,922	17.7	320	783
	Farm – Abattoir	8,442	77.8	299	767
	Farm – Market	234	2.2	247	519
	Market – Abattoir	243	2.2	404	715
	Market – Farm	6	0.1	433	493
Scotland – Wales	**Overall**	**6**	<0.1	**49**	**438**
	Farm – Farm	6	100.0	49	438
Wales – England	**Overall**	**11,991**	38.2	**49**	**438**
	Farm – Farm	1,941	16.2	58	438
	Farm – Abattoir	7,219	60.2	41	380
	Farm – Market	2,574	21.5	62	331
	Market – Abattoir	124	1.0	295	337
	Market – Farm	132	1.1	118	348
	Market – Market	1	0.0	203	203
Wales – Scotland	**Overall**	**4**	<0.1	**430**	**603**
	Farm – Farm	4	100.0	430	603

Note: The movement types with missing records were omitted from the table.

The type of movements that occurred more commonly, between countries, were farm-to-

abattoir (>51%) and farm-to-farm (>16%), as in the within-country movements. A large proportion of farm-to-market movements occurred from farms in Wales to markets in England (21%) and market-to-farm occurred from markets in England to farms in Wales (18%) (Table 9).

The figures 1) number of movements, 2) pigs per movement (batch size), 3) in/out degree and 4) total number pigs moved monthly were calculate for each CPH and expressed as an average over all CPHs in each country, for each type of movement.

The median number of movements into/out of a farm per month was only one for the whole of GB; England had the highest median of monthly movements into abattoirs (24), followed by Wales (14) and Scotland (4); Wales had the highest maximum number of monthly movements from Farm to Market (21) (Table 10).

Table 10 – Number of monthly movements per CPH, country and movement type (2006-2011 data).

	From Farm Out to						**Incoming to**					
	Farm		**Abattoir**		**Market**		**Farm**		**Abattoir**		**Market**	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
England	2	22	1	46	1	15	1	170	24	926	1	243
Scotland	1	14	1	27	1	4	1	50	4	394	2	39
Wales	1	5	1	13	1	21	1	7	14	84	1	33

The median batch size of the between farm moments (out to and incoming) was equal within countries. Scotland sent larger batches to markets (8 pigs/batch) than England and Wales; abattoirs in Scotland also received larger batches (median=18 and max=668) than England (median=10 and max=299) (Table 11).

Table 11 – Monthly batch size per CPH, country and movement type (2006-2011 data).

	From Farm Out to						**Incoming to**					
	Farm		**Abattoir**		**Market**		**Farm**		**Abattoir**		**Market**	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
England	3	1,759	3	650	6	500	3	3,003	10	299	6	187
Scotland	3	831	3	1,216	8	231	3	1,864	18	668	6	28
Wales	2	1,637	3	347	5	207	2	1,036	5	242	6	84

The number of sources (in-degree) and destinations (out-degree) was assessed for each type of CPH. The median in and out degree for farm and markets was one; the median in-degree for abattoirs was 24 for English abattoirs, 14 for Welsh abattoirs and 4 for Scottish abattoirs. Regardless of the type of movement, England always had the highest in and out degree, followed by Scotland and Wales (Table 12).

Table 12 – Monthly in-degree and out-degree per CPH, country and holding type (2006-2011 data).

	From Farm Out to						Incoming to					
	Farm		Abattoir		Market		Farm		Abattoir		Market	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
England	1	21	1	38	1	7	1	162	24	832	1	230
Scotland	1	14	1	17	1	4	1	50	4	394	2	39
Wales	1	5	1	12	1	2	1	7	14	83	1	32

Finally, the total number of pigs moved in a month was calculated for each holding. The median values for number of pigs moved from and to farms were low (between 2 and 10); the abattoirs in England received a median of 197 pigs per month, whereas the Scottish and Welsh abattoirs received a median of 91 and 87 pigs per month, respectively; the number of pigs moved in or out of markets was low (between 6 and 14) (Table 13).

Table 13 – Monthly number of pigs moved per CPH, country and holding type (2006-2011 data).

	From Farm Out to						Incoming to					
	Farm		Abattoir		Market		Farm		Abattoir		Market	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
England	4	5,908	3	6,500	7	1,148	3	6,005	197	107,073	13	3,168
Scotland	5	2,659	4	2,765	10	403	3	4,255	91	48,631	8	543
Wales	3	1,637	3	1,021	6	207	2	1,036	87	962	14	220

D. Descriptive analysis – with 2008 data

In order to study the differences between the different sectors of the pig industry a holding categorisation was applied to farms regarding their size and type (i.e. breeder, breeder-finisher and finisher), abattoir size and gathering size. For practical reasons, one year sample of the data (2008) was chosen for the descriptive analysis taking into account the holding categorisation. The results are described below.

Farm size categorisation

In order to proceed with the farm size categorisation, the distribution of the total number of animals moved (in and out) from each farm was explored and a skewed pattern was observed: a great deal of farms had a low number of animals moved, whereas a small number of farms had a high numbers of animals moved. The farms present in the QA dataset were used as a reference for the largest producers, i.e. the ones that embody the commercial producers and theoretically have more pigs moved. A data-driven threshold was found for the assured producers – the total number of animals moved exceeded 1000 for 75% of these producers; therefore, all RADAR farms above this value were considered "Large". The farms that were not present in the QA dataset were used in the same manner to identify the threshold for the "Small" producers, characterised for having <35 animals as their total number of animals moved. The farms having the total number of animals moved in the range [35 - 1000], were considered "Medium" producers. The proportions for the totality of farm CPH (18,565) were: 2,470 (13%) "Large", 3,486 (19%) "Medium" and 12,609 (68%) "Small".

The main movement figures, which are shown in Tables 14 and 15 and Figure 4, can be summarised as follows:

- the higher percentage of farm-farm movements are observed between large producers;
- the farm-farm movements between large, and between large and medium, producers are the ones that have the higher proportion of animals being transported;
- the large producers are responsible for the majority of the number of movements and number of animals moved from farm to abattoir;
- the medium producers have the higher proportion of movements between farm and gathering holdings;
- the small producers do not have a large number of movements or animals moved; however, there are a small number of movements from small to medium and large producers[12];

[12] These types of unexpected movements should be explored in order to see if they might pose a higher risk of disease transmission, or whether they are genuine movements or just errors in the database.

- the large producers have a much higher median number of animals transported per movement compared with the other categories;
- the movements between large producers or from large to abattoir are the ones with the largest distance travelled. The small producers have the smallest distances travelled irrespective the type of movement.
- The farm distribution was assessed using the number of farms per county considering the coordinates available (Figures 5-7). Observing the proportion of all farms, England has the greatest number of farms per county, followed by Wales and Scotland. When assessing the farm distribution accounting for size categories it is possible to observe that the regions with highest counts are different for the large and small producers: 1) for the large producers, the Yorkshire and Norfolk regions in England and Aberdeenshire in Scotland are those with highest number of farms; 2) Devon and Cornwall in England and Dyfed in Wales are the regions with the highest number of small producers; 3) the medium producers are spread throughout England with a low number of farms per county and the highest numbers in Yorkshire and Devon; there are much lower numbers in Scotland and Wales.

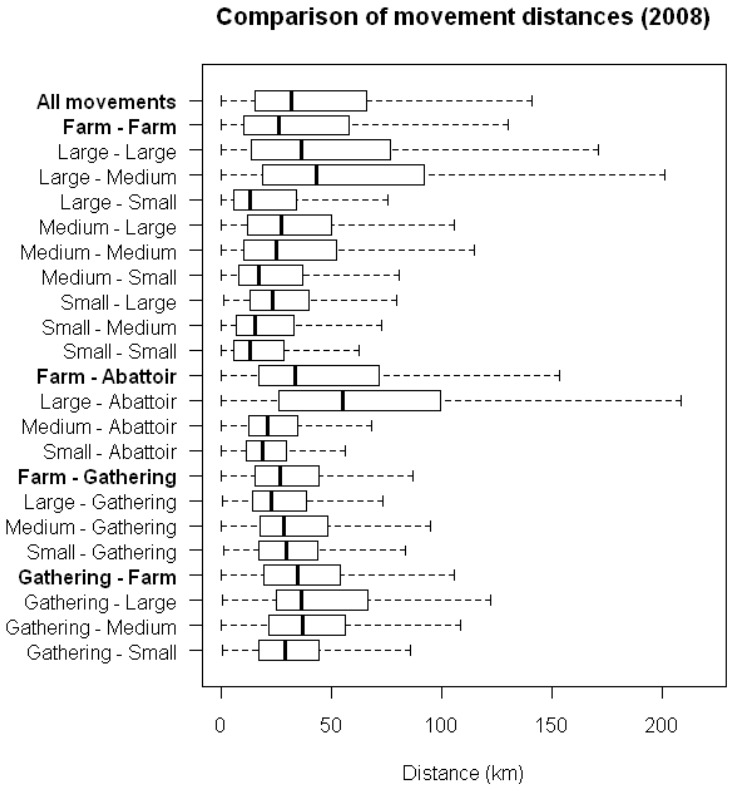

Figure 4 – Boxplot of movement distances (2008 data). Note: The graph is truncated at 300 km, the outliers are not represented.

Table 14 – Movements, animals and animals per movement figures for each type of movement in the year 2008 in GB

Type of Movements			Movements		Animals		Animals per movement (Median)
			Number	Proportion (%)	Number	Proportion (%)	
Total Movements			**203,682**	**100.00%**	**13,961,232**	**100.00%**	**15**
Farm	→	**Farm**	**38,680**	**18.99%**	**5,386,767**	**38.58%**	**19**
Large	→	Large	21,232	10.42%	5,157,851	36.94%	200
Large	→	Medium	1,462	0.72%	99,772	0.71%	12
Large	→	Small	451	0.22%	1,854	0.01%	3
Medium	→	Large	1,641	0.81%	67,988	0.49%	10
Medium	→	Medium	2,289	1.12%	23,633	0.17%	6
Medium	→	Small	5,306	2.61%	16,790	0.12%	2
Small	→	Large	424	0.21%	1,874	0.01%	3
Small	→	Medium	1,404	0.69%	5,317	0.04%	2
Small	→	Small	4,471	2.20%	11,688	0.08%	2
Farm	→	**Abattoir**	**142,865**	**70.14%**	**8,112,689**	**58.11%**	**20**
Large	→	Abattoir	85,350	41.90%	7,693,543	55.11%	76
Medium	→	Abattoir	40,140	19.71%	368,924	2.64%	4
Small	→	Abattoir	17,375	8.53%	50,222	0.36%	2
Farm	→	**Gathering**	**13,285**	**6.52%**	**150,505**	**1.08%**	**7**
Large	→	Gathering	4,441	2.18%	79,018	0.57%	10
Medium	→	Gathering	6,986	3.43%	62,650	0.45%	7
Small	→	Gathering	1,858	0.91%	8,837	0.06%	3
Farm	→	**Other**	**1,038**	**0.51%**	**23,305**	**0.17%**	**NA**
Gathering	→	**Gathering**	**9**	**0.0044%**	**49**	**0.0004%**	**5**
Gathering	→	**Farm**	**4,414**	**2.17%**	**46,366**	**0.33%**	**6**
Gathering	→	Large	639	0.31%	15,856	0.11%	19
Gathering	→	Medium	2,459	1.21%	24,082	0.17%	7
Gathering	→	Small	1,316	0.65%	6,428	0.05%	4
Gathering	→	**Abattoir**	**2,540**	**1.25%**	**99,785**	**0.71%**	**32**
Gathering	→	**Other**	**5**	**0.00%**	**67**	**0.00%**	**NA**
Abattoir	→	**Abattoir**	**75**	**0.04%**	**9,518**	**0.07%**	**125**
Abattoir	→	**Farm**	**1**	**0.0005%**	**61**	**0.0004%**	**61**
Abattoir	→	Large	1	0.0005%	61	0.0004%	61
Abattoir	→	**Gathering**	**2**	**0.0010%**	**100**	**0.0007%**	**NA**
Abattoir	→	**Other**	**0**	**0%**	**0%**	**0%**	**NA**

Note: “Other” departure is not represented due to its small representativeness (0.89% of movements and 1.11% of animals).

Table 15 – Distance figures for each type movement in year 2008 in GB.

Type of movement			Movements		Distance (km)	
			Number	Proportion (%)	Median	Max
All			**45,861**	**100.00%**	**28**	**716**
Farm	→	**Farm**	**18,762**	**40.91%**	**24**	**689**
Large	→	Large	5,680	12.39%	45	637
Large	→	Medium	688	1.50%	52	627
Large	→	Small	352	0.77%	13	376
Medium	→	Large	511	1.11%	39	358
Medium	→	Medium	1,446	3.15%	28	575
Medium	→	Small	4,534	9.89%	17	689
Small	→	Large	275	0.60%	25	352
Small	→	Medium	1,176	2.56%	16	441
Small	→	Small	4,100	8.94%	13	676
Farm	→	**Abattoir**	**20,127**	**43.89%**	**29**	**581**
Large	→	Abattoir	6,701	14.61%	73	581
Medium	→	Abattoir	4,439	9.68%	28	474
Small	→	Abattoir	8,987	19.60%	19	408
Farm	→	**Gathering**	**3,984**	**8.69%**	**34**	**454**
Large	→	Gathering	617	1.35%	33	453
Medium	→	Gathering	2,083	4.54%	38	422
Small	→	Gathering	1,284	2.80%	30	345
Farm	→	**Other**	**290**	**0.63%**	**16**	**605**
Gathering	→	**Gathering**	**2**	**0.00%**	**192**	**202**
Gathering	→	**Farm**	**2,378**	**5.19%**	**35**	**422**
Gathering	→	Large	62	0.14%	45	344
Gathering	→	Medium	1,232	2.69%	42	422
Gathering	→	Small	1,084	2.36%	29	299
Gathering	→	**Abattoir**	**162**	**0.35%**	**49**	**716**
Gathering	→	**Other**	**3**	**0.01%**	**32**	**40**
Abattoir	→	**Abattoir**	**2**	**0.004%**	**79**	**111**
Abattoir	→	**Farm**	**1**	**0.002%**	**15**	**15**
Abattoir	→	Large	1	0.002%	15	15
Abattoir	→	**Gathering**	**2**	**0.004%**	**50**	**82**
Abattoir	→	**Other**	**0**	**0.00%**	**0**	**0**

Note: “Other” departures are not represented in the table (0.32% of paths).

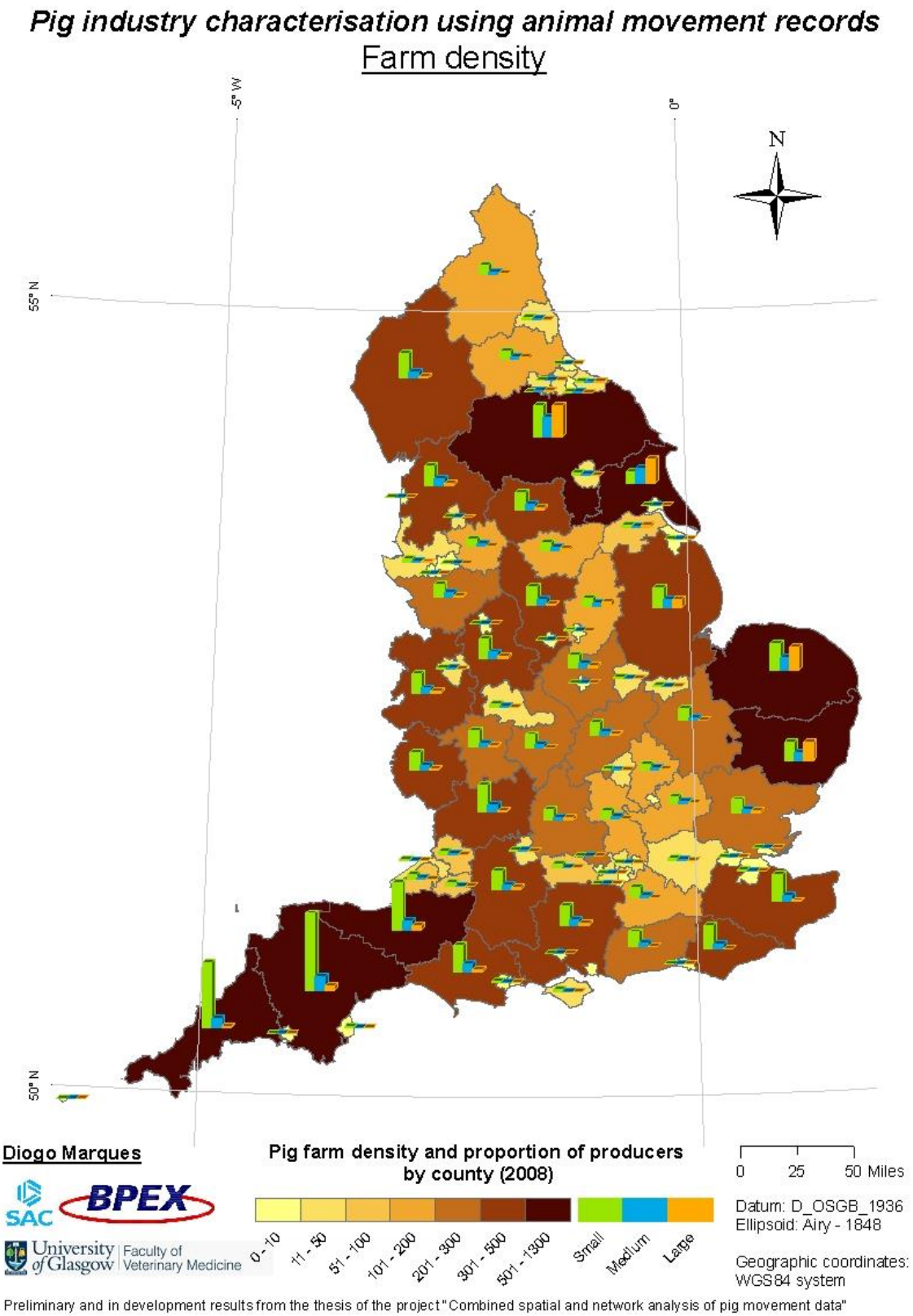

Figure 5 – English pig farm density (number of pig farms - choropleth map) and proportion of pig producers (large/medium/small - colour bar chart) by English county for the year 2008

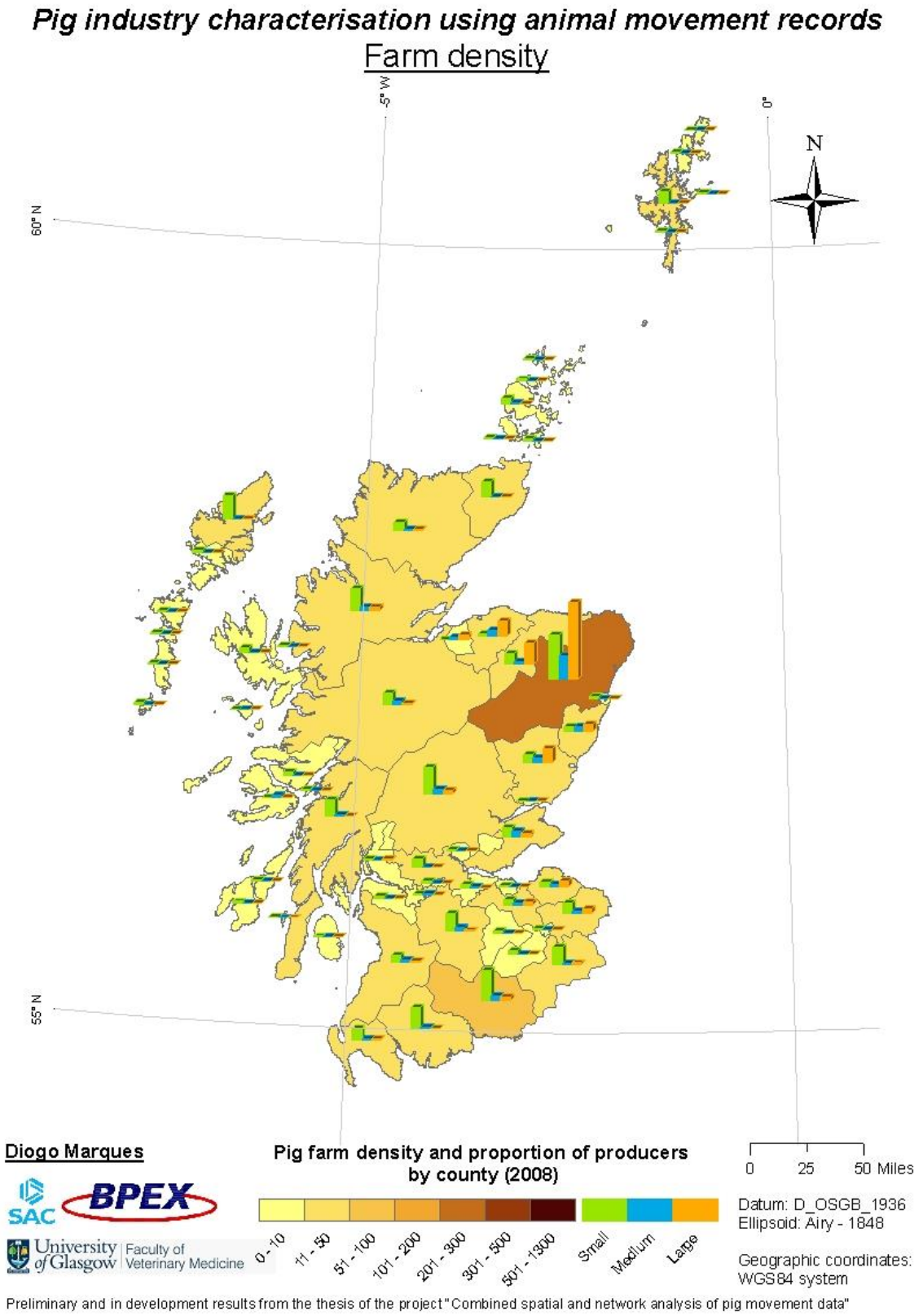

Figure 6 – Scottish pig farm density (number of pig farms - choropleth map) and proportion of pig producers (large/medium/small - colour bar chart) by county (before 1975) for the year 2008

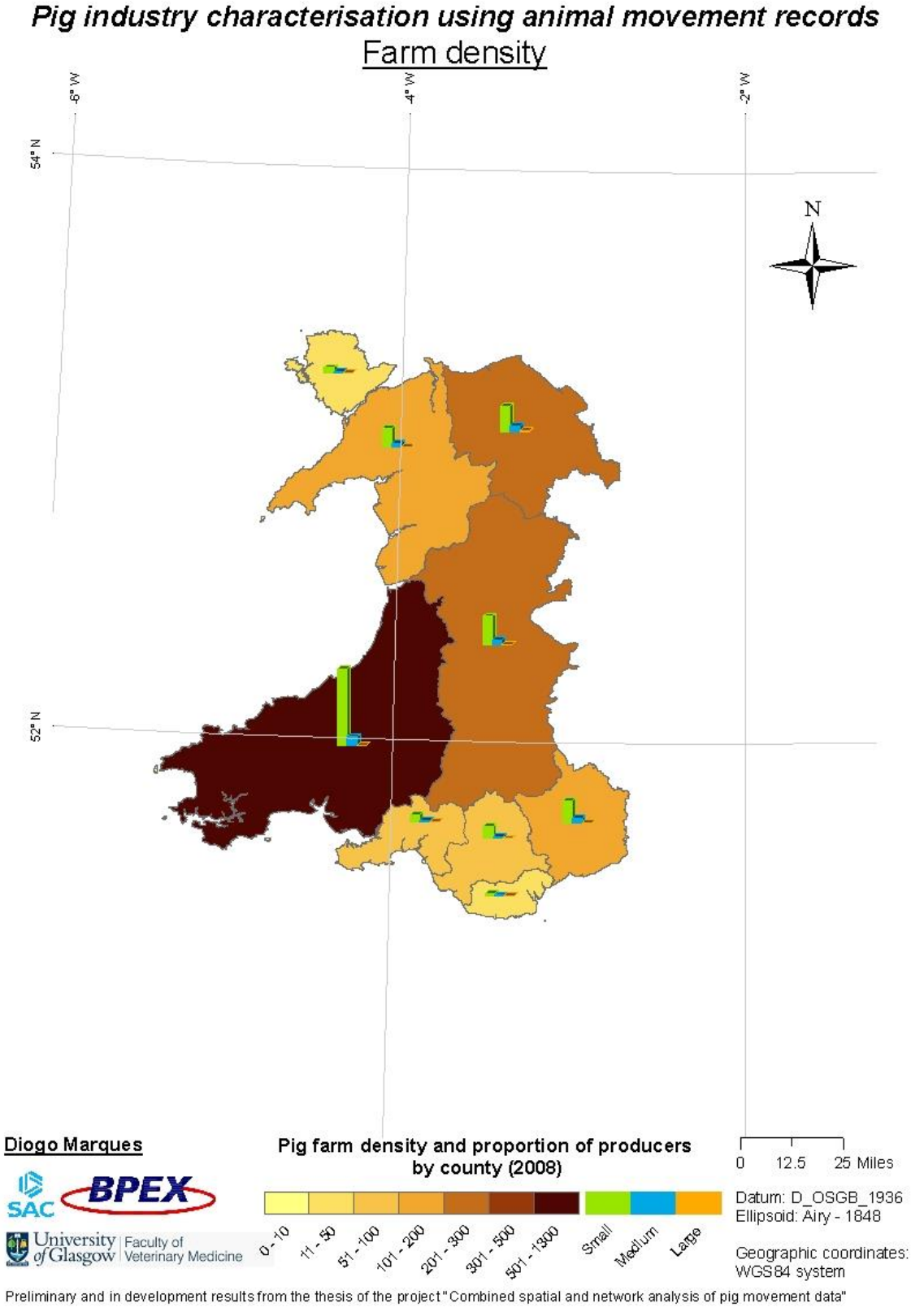

Figure 7 – Welsh pig farm density (number of pig farms - choropleth map) and proportion of pig producers (large/medium/small - colour bar chart) by county for the year 2008

Discussion/Conclusions

The main dataset used in the project was pig movement data in GB – RADAR dataset, which incorporates information from AMLS and SAMS. SAMS has been replaced by ScotEID in Scotland so caution should be taken in the interpretation of some results from this project. Some inconsistencies were found in the data and a cleaning process had to be performed. Those inconsistencies, mentioned in this report, should be fed back to the data providers to improve the quality of the data for future use. Other datasets were acquired to verify the quality of RADAR data. After this exercise the RADAR dataset was considered a useful source for analysing the pig movements in GB and therefore it was used for the descriptive analysis.

The description of British pig holdings regarding their demographic, spatial and network structure, over 2008 to 20011, showed that the number of holdings included in the movement database varied over the years but, overall, as we would expect, the farm CPHs accounted for the majority of the CPHs in the movement dataset. The majority of the movements were towards abattoirs as were, also, the majority of the animals moved. Movement between farms accounted for almost all the remaining movements and movements to and from markets were around 1% of the total. This is in accordance with what is expected from the swine sector. The majority of pig farms were located in England, followed by Wales and Scotland, as has been described in the Agricultural Census (Defra, 2009b).

In GB the majority of the pig farms have five or more neighbouring farms in a 3km radius, which can contribute to the dissemination of airborne diseases. This is a structural problem that is not easily solved, but must be taken into consideration for control of exotic and endemic disease. In Scotland this high concentration of farms is not so evident.

The majority of the regions trade between themselves and the majority of movements between regions occurred when pigs were moved from markets to abattoirs. This pattern suggests a lower risk of between-region spread of disease. This is also highlighted by only 14% of the movements involving distances of over 100 km. England had a higher risk of disease incursion from other countries (Wales and Scotland) as the majority of movements between countries had England as destination. Even, so this interconnection between countries in GB showed that disease control programmes should be implemented on a GB-wide basis.

Abattoirs in general receive more animals than farms and markets, as would be expected, and regardless of the type of movement, England always had the highest in and out degree, followed by Scotland and Wales.

The farms were categorised based on their membership of quality assurance schemes and on number of pigs moved. The farm categorisation used considers the gross quantity of pigs

that pass through a farm in one year as a rough proxy for the farm size and this can, therefore, be used to identify those regions in which the largest/smallest producers are located and which hypothetically have more/less pigs. This type of categorisation has two drawbacks, however: 1) the QA dataset does not include all assurance companies and some producers might be misclassified as Medium producers; 2) the total number of animals moved per year is not the best proxy for herd size for all types of production, except for finisher producers (e.g. when comparing a breeder unit with finisher unit, both could be considered large commercial units, but the latter might be considered Large because it will have pigs being moved in and out of the farm, whereas the former might be considered Medium for only having pigs being moved out of the farm). Thus, farm categorisation should take into consideration the ratio of movements in and out to determine both the farm size, as well as the likely type of production (i.e. breeder, breeder-finisher and finisher). As expected the majority of farms were classified as small and a small proportion as large. The Agricultural Census statistics (Defra, 2009b) had already highlighted this fragmented structure of the pig industry in GB.

Large producers are responsible for the majority of the animals moved, frequently transporting a large number of animals either for slaughter or to other premises and travelling larger distances to get their pigs marketed. In contrast, small producers are characterised by a low number of movements, with a low number of pigs per batch and shorter distances travelled. Based on these outlines, an undetected disease incursion spreading via large producers could generate widespread epidemics through exposure of a large number of farms and animals, whereas as incursion occurring in small producers would be limited and less likely to involve wide geographic spread.

When accounting for size categories in the assessment of farm distribution it was observed that the Yorkshire and Norfolk regions in England and Aberdeenshire in Scotland were those with highest number of large producers; while Devon and Cornwall in England and Dyfed in Wales were the regions with the highest number of small producers. The medium producers were spread throughout England with a low number of farms per county and the highest numbers in Yorkshire and Devon; there was much lower number of medium producers in Scotland and Wales.

This project has showed the value of movement data for the characterization of denominator data (i.e. number of active pig holdings) and the different types of producers. The results also showed that there was an interconnection between the different types of producers in terms of movements, particularly the unexpected movements between large producers (believed to belong to quality assurance schemes and therefore with a higher biosecurity) and small producers (believed to have a lower biosecurity status and therefore more prone to introduction and spread of undiagnosed disease). Furthermore, the network analysis showed

that medium producers had a higher proportion of movements to small and large producers than the inverse. It is plausible, therefore, that medium producers may represent a bridge between the large and small producers of the pig industry, potentially allowing undiagnosed pathogen to spread throughout the industry. A risk-based approach is recommended for consideration within future monitoring programmes, particularly for exotic disease.

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Annex I – Some of the presentations done

1. BPEX Post Graduate Seminar, 2009: Combined Spatial and Network Analysis of British Pig Movement Data
2. The Association for Veterinary Teaching and Research Work (AVTRW) Annual Conference 2010: Pig industry characterization by spatial and social network analysis: Data validation process and descriptive analysis preliminary results
3. SAC Post Graduate Conference 2011: Great Britain pig movement data analysis: network description

Combined Spatial and Network Analysis of British Pig Movement Data

BPEX Post Graduate Seminar

Diogo Marques
MSc Student

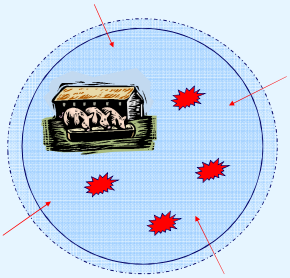
07 December 2009

Chesford Grange Hotel, Kenilworth, Warwickshire

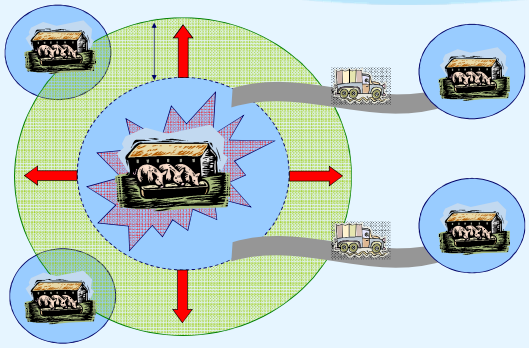
Background

Outbreak trigger

- From inside the herd
- From outside the herd

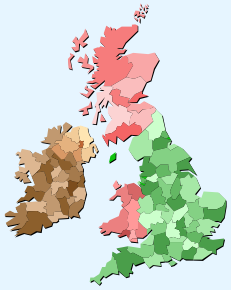


Background



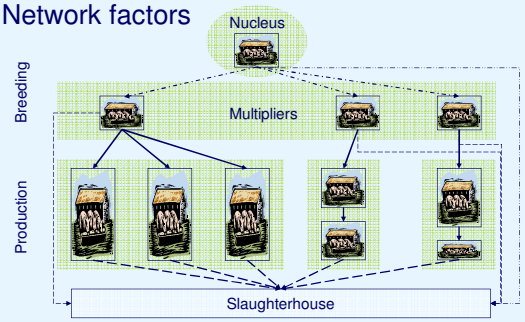
Background

Spatial factors



Background

Network factors



Background

Project outline

Main objective

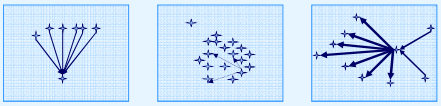
Investigate the impact that
the **Network** and **Spatial structure**
have on the disease prevalence across the pig industry

Project outline

- Data cleaning and data analysis
- Descriptive analysis of the data:
  - Characterization of the Pig Industry – "Picture of the reality"
    - Number of Holdings
    - Number of Movements
    - Number of Animals
    - Number of Animals per Movement

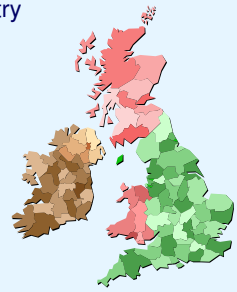
Project outline

- Network Analysis of Pig Industry
  - Weaknesses
  - Holding number reduction
  - Disease eradication
  - Disease spread
  - Holding risk index



Project outline

- Spatial Analysis of Pig Industry
  - Spatial characteristics:
    - Disease introduction
    - Disease spread
    - Disease maintenance



Project outline

- Spatial / Network characteristics Vs Disease
  - What diseases?
    - Abattoir lesions reported in BPHS
    - Special attention to respiratory diseases
  - Our questions
    - Are the conditions clustered spatially?
    - Is there any network structure contributing to the risk?
    - What is the weight between spatial and network structure?

Outputs

- Main outputs
  - To have an available database
  - To have a “Picture of the reality” of pig industry
    - Based on pig movements
  - Possible correlations
    - Disease ↔ Network Vs Spatial

Outputs

- Other potential outputs
  - Through disease modelling
    - Support decisions during outbreak;
    - Study hypothetic scenarios:
      - Disease effect on the network;
      - Disease behaviour within the network;

Outputs

- Other potential outputs:
  - To specific pig groups:
    - How would their network react to control measures?
      - E.g. movement ban;
    - Evaluate the disease impact in their network;
    - Study the best preventive measures to be applied;

Outputs

- Other potential outputs:
  - Improve control measures with:
    - Risk-based interventions
      - Prioritise the types of measures;
      - Prioritise holdings where measures need to be implemented;
  - Improve pathogen surveillance;
  - Improve general industry management.

The End

Thank You


SAC
Success through Knowledge
BPEX

Pig industry characterization by spatial and social network analysis

Data validation process and descriptive analysis preliminary results

Diogo Marques

Epidemiology Research Unit – SAC – Inverness

Faculty of Veterinary Medicine – University of Glasgow

Objective

Project main objective

Investigate the impact that
the **Network** and **Spatial structure**
have on the disease prevalence across the pig industry

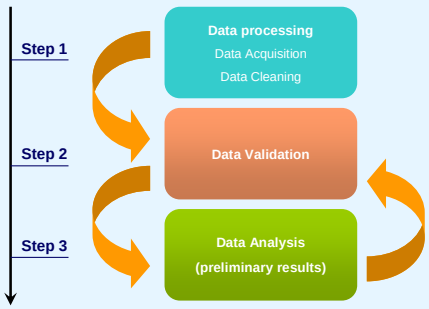
Objective

First stage objective

Pig Industry characterization by **descriptive analysis** through Animal Movement Records

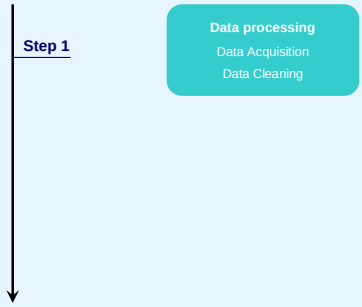
Study Outline

Study Outline



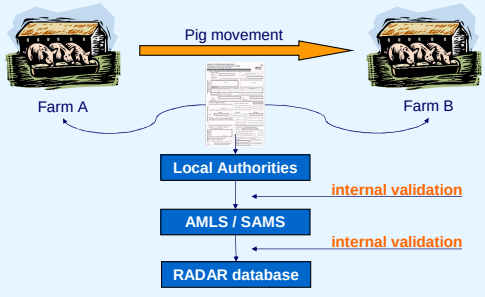
Study Outline

Study Outline



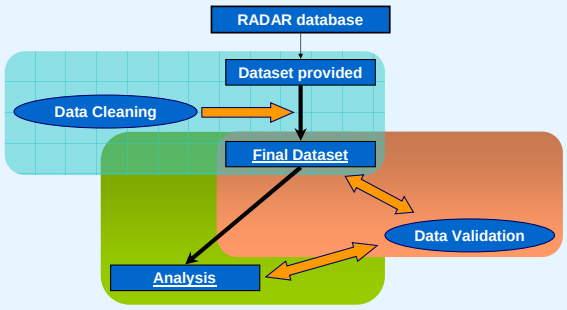
Step 1 - Data processing

Data Acquisition



Step 1 - Data processing

Data Acquisition



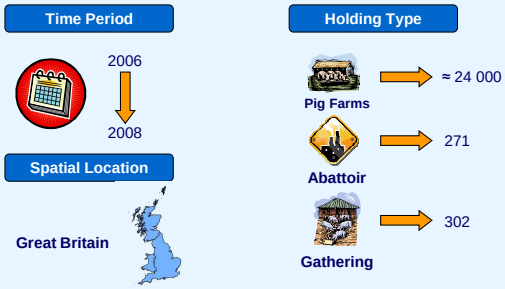
Step 1 - Data processing

Data Cleaning

- **Objectives:**
  - Detection and correction of possible errors
  - To obtain an accurate and representative dataset
- **Methods:**
  - Removal of farms with only 1 movement reported
  - Correction of miss-classified holding types
  - Removal of irrelevant movements
    - E.g. Same holding as departure and destination

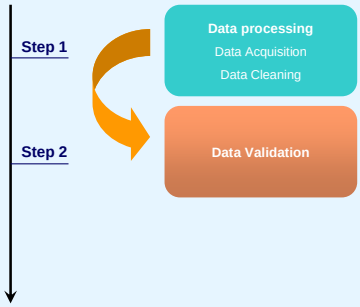
Step 1 - Data processing

Data exploration – main figures

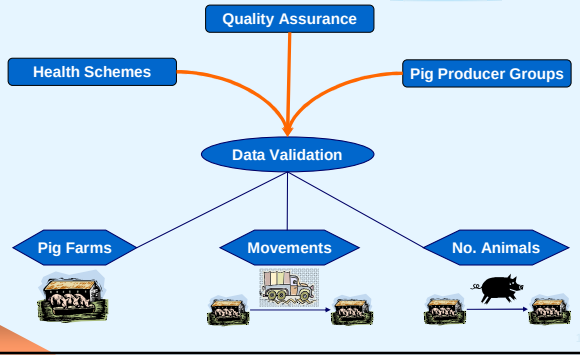


Study Outline

Study Outline



Step 2 - Data Validation



Step 2 - Data Validation

Pig Farms

- Objective
  - To identify the professional producers
- Sources of validation
  - Quality Assurance (ABP and QMS)
  - Pig Producer Groups (A and B)
  - Health Schemes (BPHS and WPS)

Step 2 - Data Validation

Pig Farms

- Process
  - Match between CPH codes in both datasets
- Results
  - Number of farms matched – 2,235 (8.8%)
  - **Representativeness** of those farms:
    - **Movements** – 308,254 (**51%**)
    - Overall **animals** moved – 36,749,800 (**86%**)
    - Animals entering **abattoir** – 16,405,695 (**65%**)

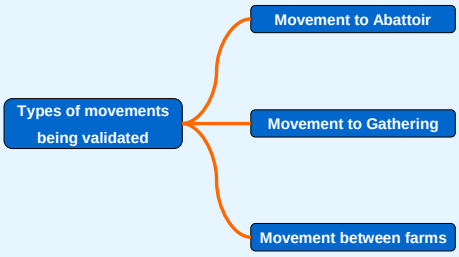
Step 2 - Data Validation

Movements and No. Animals moved

- Objective
  - To assess the reliability on the animal **movements** and the **number of animals** reported of the final dataset
- Sources of validation
  - Pig Producer Groups (A and B)
  - Health Schemes (BPHS and WPS)

Step 2 - Data Validation

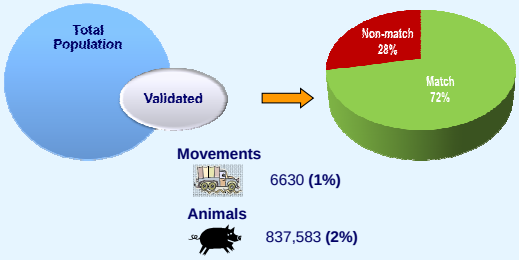
Movements and No. Animals moved



Step 2 - Data Validation

Movements and No. Animals moved

- Results:



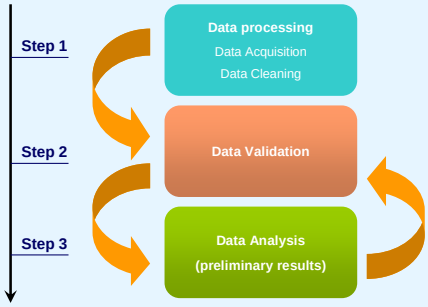
Step 2 - Data Validation

Conclusions

- Agreement
  - Good agreement between government and private data
- Non-matching records
  - Reasons for non-matching records are being evaluated
    - Possible data errors in the databases
    - "Death on arrival" animals

Study Outline

Study Outline



Step 3 - Data Analysis

Descriptive Analysis

- Objective
  - Explore the animal movements:
    - Between pig farms
    - Between pig farm and abattoir
    - Between pig farm and gathering
    - Between gathering and pig farm
- Time Period: Year 2008

Step 3 - Data Analysis

Descriptive Analysis

- Categorization of farms
  - Considering:
    - total number of movements
    - total number of animals transported per movement
  - Categories:
    - Large
    - Medium
    - Small

Step 3 - Data Analysis

Descriptive Analysis

- Categorization of farms – process
  - Considering the "professional producers"
    (ABP, QMS, BPHS, WPS, Pig Producer Groups)
    - Large
      - Total number of **Animals** moved **> 1000**
      - Total number of **Movements** in 2008 **> 20**
  - Considering "non-professional producers"
    - Small
      - Total number of **Animals** moved **< 25**
      - Total number of **Movements** in 2008 **< 5**

Step 3 - Data Analysis

Descriptive Analysis

- Categorization of farms – process
  - Medium
    - Total number of **Animals** moved **[25 – 1000]**
    - Total number of **Movements [5 – 20]**

Step 3 - Data Analysis

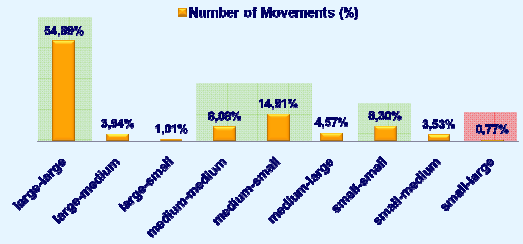
Descriptive Analysis

- Categorization of farms
  - Categories Vs **"professional producers"** (1,954)
    - Large – 1,485 (76%)
    - Medium – 390 (20%)
    - Small – 79 (4%)
  - Categories Vs **All Farms** (18,565)
    - Large – 2,470 (13%)
    - Medium – 4315 (23%)
    - Small – 11,780 (63%)

Step 3 - Data Analysis

Descriptive Analysis

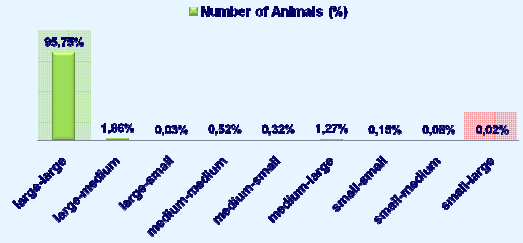
- Movements – **Between farms**



Step 3 - Data Analysis

Descriptive Analysis

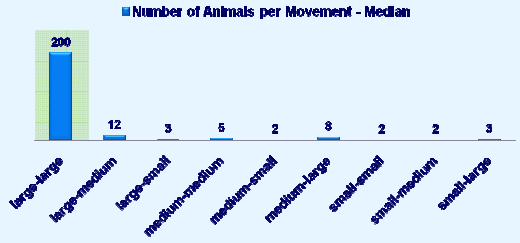
- Movements – **Between farms**



Step 3 - Data Analysis

Descriptive Analysis

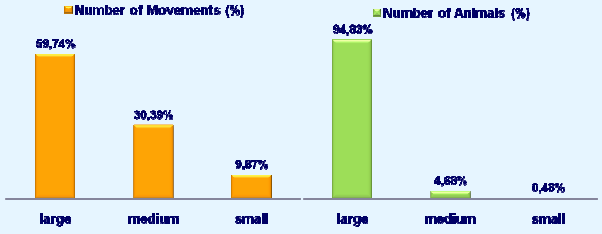
- Movements – **Between farms**



Step 3 - Data Analysis

Descriptive Analysis

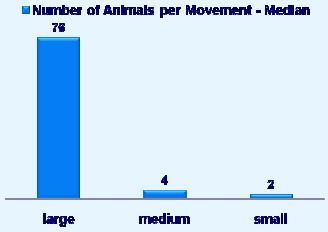
- Movements – **Farm to Abattoir**



Step 3 - Data Analysis

Descriptive Analysis

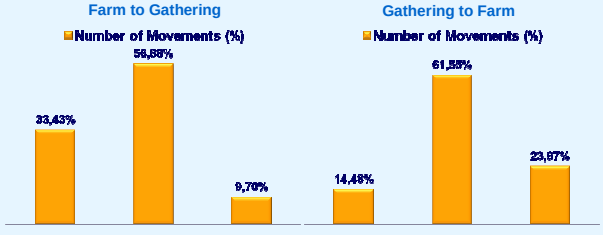
- Movements – **Farm to Abattoir**



Step 3 - Data Analysis

Descriptive Analysis

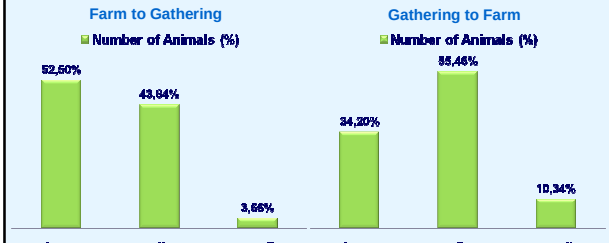
- Movements



Step 3 - Data Analysis

Descriptive Analysis

- Number of Animals



Step 3 - Data Analysis

Descriptive Analysis

- Conclusions
  - Preliminary results provide an approximated idea of the interactions within the pig industry network
  - The interactions observed suggest an industry dominated by a small number of “large” producers but with relations with “small” and “medium” producers

Further Steps

Further Steps

- Use of **Social Network Analysis** parameters to quantify the relations between farms and other types of holdings
- Explore the interactions between holdings by **Spatial Analysis**
- Explore the impact that the network and spatial characteristics have on **disease prevalence** (e.g. respiratory diseases)

Acknowledgements

Special Thanks to:

- BPEX – project funder
- Project Supervisors
  - Manuel Sanchez
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  - Rowland Kao
  - Sandra Edwards
  - Jill Thomson
  - George Gunn
- RADAR
- Pig Group Producers

Thank You!

Great Britain pig movement data analysis: network description

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Introduction

Pig production in Great Britain (GB) is not a closed system restricted by physical barriers or geographical boundaries. Interactions may occur between neighbouring farms (share environmental or topographical conditions) or through animal contacts (pig movements). These interactions should be analyzed and taken into account when studying disease occurrence or providing preventive and control measures.

Pig movement data is recorded countrywide and provides an opportunity to improve the knowledge about the demographic, spatial and network structure of the British pig industry.

The objective of this study was to explore the spatial and network characteristics of pig movement between different pig holdings.

Methods and Results

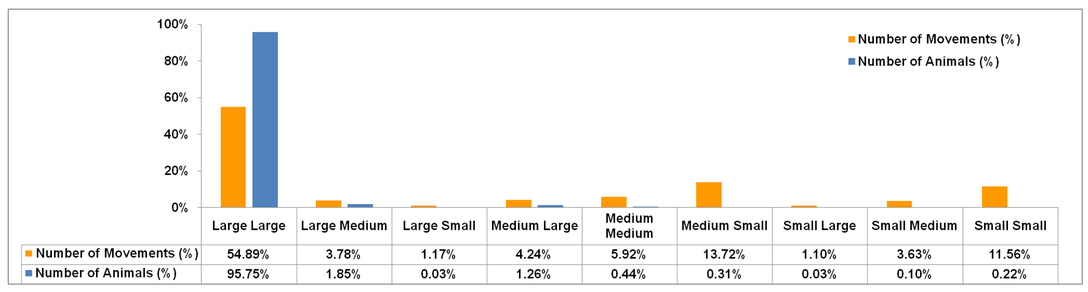
The 2008 GB pig movement records were obtained from RADAR. These data allowed identification of the "active" pig holdings, and provided information about inter-holding contacts and geographical location. The data was explored using simple descriptive analysis. The software ArcMap 9.2 and Pajek 2.0 3 were used for data visualization.

- The total number of pigs moved per year was used to categorise the holdings in Large/Medium/Small as a proxy for holding size:

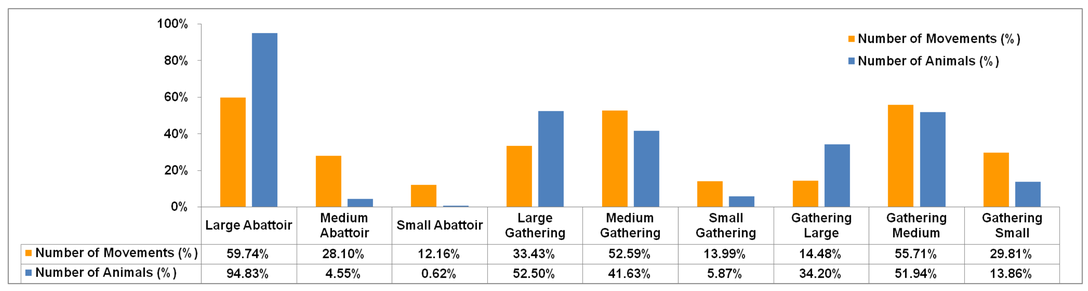
Farm category	Large	Medium	Small	Total
Criteria	> 1000	1000-35	< 35	
Number	2,470	3,486	12,609	18,565
Proportions	13%	19%	68%	100%
Abattoir category	**Large**	**Medium**	**Small**	**Total**
Criteria	> 100,000	100,000-1,000	< 1,000	
Number	16	110	74	200
Proportions	8%	55%	37%	100%
Gathering category	**Large**	**Medium**	**Small**	**Total**
Criteria	> 1000	1000-100	< 100	
Number	22	30	149	201
Proportions	11%	60%	29%	100%

- Approximately 200,000 movements and 14 million pigs were transported per year (8M from farm to abattoirs; 5M between farms and 150,000 from farm to Gathering – i.e. markets/showground);
- The Large producers were found to be responsible for the majority of farm-farm and farm-abattoir movements; the medium producers have the highest proportion of movements between farm and gathering; movements from small to medium and large producers are reported and they should be explored because they might pose a higher risk of disease transmission (Graph 1);
- Abattoir and gathering holdings are heterogeneously distributed (Figure 1 - left); There are differences in the geographical farm distribution, e.g. small Vs large producers (Figure 1 - right);
- The visualization and detection of network patterns on the full network is not practical (Figure 2 - left). The identification of small groups within the network together with network analysis will provide a better picture of the British pig industry (Figure 2 - right).

Graph 1 - Number of movements and animals moved between farm, abattoir and gathering holdings



	Large Large	Large Medium	Large Small	Medium Large	Medium Medium	Medium Small	Small Large	Small Medium	Small Small
Number of Movements (%)	54.89%	3.78%	1.17%	4.24%	5.92%	13.72%	1.10%	3.63%	11.56%
Number of Animals (%)	95.75%	1.85%	0.03%	1.26%	0.44%	0.31%	0.03%	0.10%	0.22%



	Large Abattoir	Medium Abattoir	Small Abattoir	Large Gathering	Medium Gathering	Small Gathering	Gathering Large	Gathering Medium	Gathering Small
Number of Movements (%)	59.74%	28.10%	12.16%	33.43%	52.59%	13.99%	14.48%	55.71%	29.81%
Number of Animals (%)	94.83%	4.55%	0.62%	52.50%	41.63%	5.87%	34.20%	51.94%	13.86%

Figure 1 – Spatial distribution of abattoirs and gathering holdings (left); Spatial distribution of large and small producers (right)

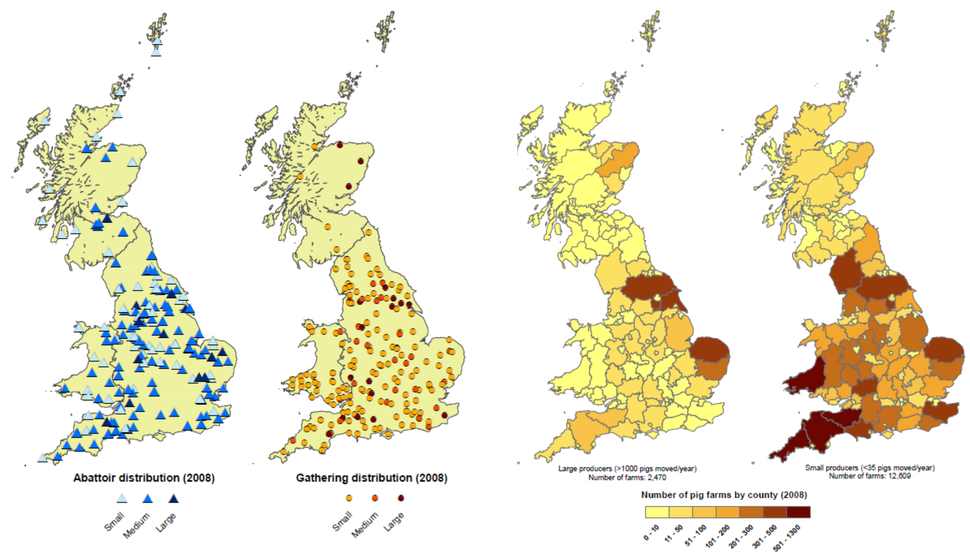
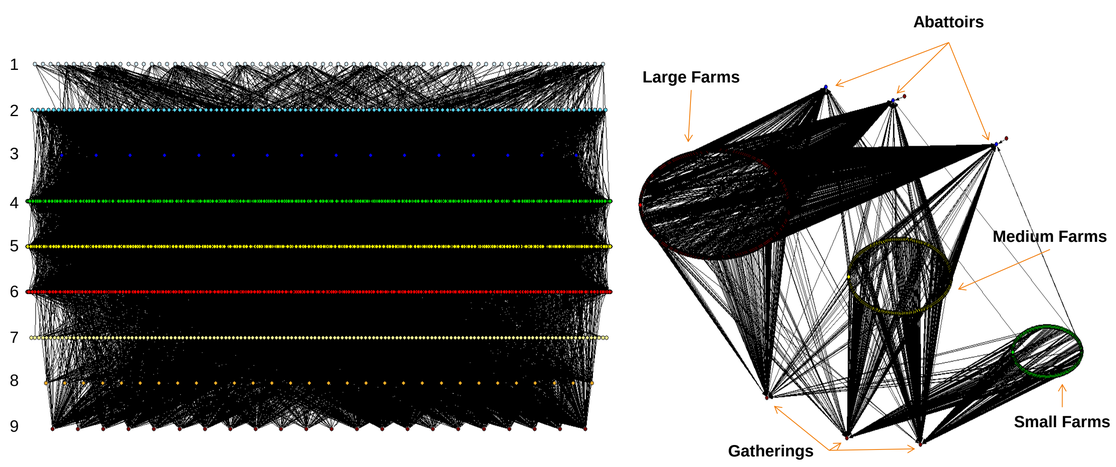


Figure 2 – Complete network representation (left) - the symbol colours represent different types of holding categories (1,2,3 - abattoirs (small/medium/large), 4,5,6 - farms (s/m/l) and 7,8,9 - gathering (s/m/l)), and black lines the links between them; Example of small network between Abattoir, Farms and Gathering holdings (right);



Future Work

- The data will be explored considering the animal flow between/within network communities and geographical regions;
- Other parameters - spatial (e.g. spatial proximity to other holdings) and network (e.g. clustering coefficient) - will be used to finalize the characterization of the links between holdings in the GB pig industry.

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