Infection Through the Farm Gate

Studies on Movements of Livestock and On-farm Biosecurity

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Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2010

Acta Universitatis agriculturae Sueciae
2010:11

ISSN 1652-6880
ISBN 978-91-576-7488-3

Print: SLU Service/Repro, Uppsala 2010

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Abstract

This thesis is based on studies of movements of livestock, on-farm biosecurity and disease awareness among farmers in Sweden; factors which can affect the spread of contagious livestock diseases.

The structure of the cattle and pig movements were analysed using data obtained from the Swedish Board of Agriculture. Most movements were within 100 km, however, there were also long distance movements up to 1200 km for cattle and 1000 km for pigs. This supports an initial total standstill in case of an outbreak of foot-and-mouth disease. Network analysis was used to investigate the contact patterns. Many of the farms did not sell or buy animals or had only limited trade, whereas some farms had many contacts. The measure 'ingoing infection chain' was constructed to capture indirect movements, some farms with few direct contacts had many indirect contacts and this measure can potentially be very useful for disease control and risk based surveillance.

On-farm biosecurity was investigated through a posted questionnaire study to 1498 farmers and response was retrieved from 34% of them. Among farmers declining participation, the major reason was not having livestock. There was large variation in biosecurity routines among farmers. In general farmers with pigs had higher biosecurity compared to farmers with cattle, sheep/goats or mixed species or hobby farmers. Many farmers and visitors did not have sufficient routines to prevent spread of disease and some reported inconsistent routines, indicating a lack of knowledge of how to prevent spread of disease. A need for improvement of on-farm biosecurity was identified. Disease awareness and information retrieval among pig farmers in relation to an outbreak of PRRS in 2007 was investigated using posted questionnaires to 153 farmers. Farmers with large herds were in general aware of the outbreak and how to protect their farm. However, hobby farmers were identified as a group difficult to reach with information in case of an outbreak. Active search for information was associated with distance from the outbreak. The Swedish Animal Health Service, followed by the veterinary authorities, were considered the most important and reliable source of information.

Keywords: livestock movement, network analysis, biosecurity, disease control, awareness, ingoing infection chain, cattle, pig, sheep

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If you know exactly what you are going to do, what is the point of doing it?

Pablo Picasso

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Maria Nöremark, Nina Håkansson, Tom Lindström, Uno Wennergren, Susanna Sternberg Lewerin (2009). Spatial and temporal investigations of reported movements, births and deaths of cattle and pigs in Sweden. Acta Veterinaria Scandinavica Oct 7;51:37. http://www.actavetscand.com/content/51/1/37

II Maria Nöremark, Nina Håkansson, Susanna Sternberg Lewerin, Ann Lindberg, Annie Johnsson. Network Analysis of cattle and pig movements in Sweden; measures relevant for risk based surveillance. (Submitted manuscript).

III Maria Nöremark, Jenny Frössling, Susanna Sternberg Lewerin. Application of routines that contribute to on-farm biosecurity as reported by Swedish livestock farmers. (Submitted manuscript).

IV Maria Nöremark, Ann Lindberg, Ivar Vågsholm, Susanna Sternberg Lewerin (2009). Disease awareness, information retrieval and change in biosecurity routines among pig farmers in association with the first PRRS outbreak in Sweden. Preventive Veterinary Medicine, Volume 90, Issues 1-2, 1 July 2009, Pages 1-9.

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Abbreviations

BSE	Bovine Spongiform Encephalopathy
CSF	Classical Swine Fever
FAO	The Food And Agriculture Organization of the United Nations
FMD	Foot-and-mouth disease
GSC	Giant Strong Component
GWC	Giant Weak Component
OIE	The World Organization for Animal Health
PRRS	Porcine reproductive and respiratory syndrome
SJV	Jordbruksverket, The Swedish Board of Agriculture
SvDHV	Svenska Djurhälsovården, The Swedish Animal Health Service

1 Background

This thesis focuses on movement of livestock, on-farm biosecurity and disease awareness. To place the studies in their relevant context, a general background on control, eradication and prevention of contagious livestock diseases is given below.

1.1 Terminology

The terminology used within the field of disease control has slightly different definitions in different sources (OIE, 2009; Christensen, 2001). However, unless further specification is given, within this text the word **disease** is used with the meaning infectious contagious disease affecting livestock. The word **outbreak** is used meaning the occurrence of one or more animals infected with a specific infectious agent, with or without displaying clinical signs, in a previously free population. The word **endemic** is used with the meaning constant presence within a population or region. C**ontrol** is used for efforts in reducing frequency of disease and **eradication** for the efforts to eliminate disease from a defined population or region.

1.2 Control, eradication and prevention of diseases

1.2.1 Historical background

Disease control and eradication has a long history. One of the first diseases that had a large impact on livestock production worldwide is Rinderpest; a highly contagious bovine viral disease causing up to 100% mortality in affected cattle, and as a consequence starvation and death among people. There are different views on when rinderpest first was mentioned in written sources; some propose that it was during the epidemic 376-386, whereas others suggest that the bovine disease described already by Aristotle (384-322 BC) was actually rinderpest. Regardless of when it was first mentioned, rinderpest was a major problem in Europe for centuries and the Italian physician Giovanni Maria Lancisi (1654-1720) was the first to introduce effective measures for eradication. His recommendations included slaughter of infected animals, movement restrictions, safe disposal of carcasses and meat inspection; principles that are valid still today. In combination with strict enforcement (including severe penalties for those who did not obey), these recommendations were successful in controlling the disease. The need to control diseases was also the motive for starting the world's first veterinary school in Lyon in 1761, where the principles of Lancisi were taught. (Barrett et al., 2005) The school was attended by the Swedish apprentice of the famous Uppsala-based scientist Linnaeus, Peter Hernqvist, who was sent to France by the Swedish government in 1763 to learn the new methods of disease control and eradication and who after returning to Sweden started the first Swedish veterinary school in 1775 (Dyrendahl, 1996).

Kongl. Maj:ts
Förnyade Nådiga
Förordning,
Angående
Boskaps siuka och Fänads Päst.
Gifwen Stockholm i Råd-Cammaren then 23
Martii 1750.

Cum Gratia & Privilegio S:æ R:æ Maj:tis.

STOCKHOLM, Tryckt uti Kongl. Tryckeriet,
Hos Directeuren Pet. Momma.

Figure 1. Swedish regulation on the control of the cattle diseases 'Boskaps sjuka' and 'Fänads päst' from 1750, although not strictly defined, probably one of them refers to rinderpest. Photo reproduced with the kind permission of the Veterinary museum in Skara.

1.2.2 Motives for prevention and eradication

Even though rinderpest, through the work of The Food and Agriculture Organization of the United Nations (FAO), has come close to global eradication (FAO, 2009) contagious livestock diseases remain a problem of current interest. Since contagious livestock diseases can cause death or decreased production (e.g. slower growth, affected reproduction or drop in milk production), livestock disease outbreaks can have major impact on the livelihood of people, especially in countries where the resources are limited and where there are no systems for compensating affected farmers for their losses. This is also the reason why FAO, which has the goal to prevent hunger and achieve food security for all, is involved in control and eradiation of livestock diseases (FAO, 2010). Apart from loss of production, some of the diseases affecting livestock are zoonotic, i.e. they affect people as well as animals and transmission can occur either through direct contacts, indirect environmental contacts or via food. Controlling livestock disease can thus be an important part of ensuring food safety "from the stable to the table". Moreover, there is the animal welfare aspect; freedom from disease is part of 'the five freedoms' as defined by the Farm Animal Welfare Council (FAWC, 2010). The above mentioned motives are not a complete list why contagious livestock diseases should be prevented and controlled or eradicated; other examples are to minimise the use of antibiotics (either used against the primary disease or to treat secondary infections) and thus decrease the risk for development of resistant bacteria, or to protect endangered wild or domesticated species.

1.2.3 Global disease occurrence and spread

Several of the serious contagious livestock diseases that are controlled or have been eradicated in Western Europe occur endemically in other parts of the world. For example foot-and-mouth disease (FMD) occurs endemically in parts of Africa, Asia and South America (Rweyemamu et al., 2008). International trade with animals and products of animals, especially illegal trade where the health requirements have not been met, increase the risk of outbreaks (Arzt *et al.*, 2010; Vallat, 2009). Furthermore, environmental changes have been discussed in relation to introduction of vector-borne disease to previously free areas (Purse et al., 2008). Recent examples of large outbreaks in Western Europe are the outbreak of Classical Swine Fever in Europe in 1997-1998 (Stegeman et al., 2000) and the outbreak of FMD starting in the UK in 2001 where the likely source was illegally imported meat (Kitching et al., 2005). The losses to the agricultural sector in the UK were estimated to £3.1 billon, and 4 million animals slaughtered for disease control and 2.9 for million for welfare reasons (to prevent overcrowding in the stables due to movement restrictions) (Thompson et al., 2002).

1.2.4 Means of transmission and spread

Infected animals can secrete or excrete the infectious agent during the incubation period, during the clinical phase (which can be mild or severe) as well as during chronic infection. Thus, animals that can potentially transmit diseases to other animals do not always display clinical signs. The routes of transmission vary between diseases. Some infectious agents require direct contact between animals, whereas others can transmit through products, excretions or secretions of animals (e.g milk, meat, urine, manure, saliva, semen) or indirect through e.g. equipment, vehicles or persons that have been in contact with animals, animal products or excretions. Moreover, feed can be a vehicle of transmission for some diseases (e.g. bovine spongiform encephalopathy (BSE), and salmonella). For some diseases, insect vectors (e.g. bluetongue), play an important role in transmission. For spread, occurrence of disease in the wildlife population can be of importance, e.g. Classical Swine Fever (CSF) in wild boar (Fritzemeier *et al.*, 2000). The livestock disease considered as the most contagious of all, FMD, can in addition to direct and indirect contact, spread with the wind over fairly long distances due to the large amount of virus particles in exhaled air from infected animals, especially pigs (Donaldson & Alexandersen, 2002). However, even though windborne spread occurs, the direct and indirect contacts remain important for the spread, and especially the introduction of infectious live animals (Rweyemamu et al., 2008). The title of this thesis was inspired by a presentation by Dr. Nick Honhold at the SVEPM meeting in Warwick (2003); the strategy of contiguous culling during the FMD outbreak in the UK in 2001 based on theories of nearby spread was discussed. When tracing was done it was often revealed that infected premises had indeed had contacts with other infected premises, as concluded by Dr. Honhold (with reservation that the quote might not be exact):

> It came through the farm gate.

1.2.5 International regulations for control and eradication

An outbreak of rinderpest occurred in Belgium in 1920, caused by a transit of zebus from India destined for Brazil through the port of Antwerp. As a consequence, an international conference on the study of epizootics was held in 1921 which three years later resulted in the creation of the Office International des Epizooties, currently the World Organization for Animal Health (OIE) (OIE). The OIE is an intergovernmental organization working to promote animal health, e.g. through systems for reporting disease outbreaks and notifying other countries, systems for determining disease freedom and recommendations for international trade with animals and products of animals (OIE, 2009). In these matters the OIE is a reference organization to the World Trade Organization (OIE).

At the European Union level there is legislation regulating trade within and from outside the union as well as directives and regulations for the control and eradication of outbreaks within the union, for example FMD and CSF (Anonymous, 2003; Anonymous, 2001). Moreover, to ensure traceability, the EU requires registration of holdings and livestock movements both between and within Member states (European Commission 2010; Anonymous, 2008; Anonymous, 2000b; Anonymous, 2000a).

1.2.6 Prevention

There are two important parts in preventing disease; the first is to avoid introduction of disease to a population, country, region or farm, and the second part is to prevent further spread if disease nonetheless would be introduced. In prevention there are both 'the known' and 'the unknown' threats; i.e. diseases known to be present, and the 'exotic' or emerging diseases, the presence of which we are unaware. The prevention of 'the knowns' can be handled through international trade regulations, as well as national regulations (e.g. control programmes for endemic diseases) related to movements of animal and animal products, such as testing and quarantine, on-farm biosecurity, vaccination and vector control. Another more general preventive measure is to keep animals in good condition and free from other diseases to minimize their susceptibility to infectious disease (Mims et al., 2001). The unknown threats are more difficult to handle, as they per definition are unknown. Two examples of the 'unknowns' are BSE where both the disease and route of transmission through contaminated feed were unknown before 1986 (Bradley & Matthews, 1992), or the introduction of e.g. FMD in a previously free population before detection of the first case. However, applying basic principles to break the known routes of transmission of contagious diseases can be efficient in preventing silent spread before detection of disease in the population. Such basic principles include minimizing direct contact between live animals of different origin and of unknown disease status. How this can be achieved varies with the type of animal production. Some types of production can limit all introductions to only genetic material (semen, embryos). For other production types, isolation of animals or keeping different groups of animals separated from each other within the holding can enable the detection of clinical signs before the new animals come in contact with the rest of the herd, (i.e. if the animal is incubating a disease with a short incubation period and apparent clinical signs). Furthermore, the indirect routes of transmission should be broken, through the usage of protective clothing by farm visitors and cleaning equipment in direct or indirect contact with other herds. Recently the importance of prevention, with focus on on-farm biosecurity, has been emphasized within the EU through the new animal health policy "Prevention is better than cure" (European Commission 2007).

1.2.7 Control and eradication

The basic principle for eradication is to find all sources of infection and instigate measures to prevent further spread. The recommendations introduced by Lancisi (culling of infected animals, restriction of animal movements and safe disposal of carcasses) are still valid tools for eradication. However, for diseases where indirect spread is important, further measures will be needed to break the indirect transmission routes such as movement restrictions for vehicles and people, strict usage of protective clothing, cleaning and disinfection of equipment and premises. Further, vaccination can sometimes be used, either with subsequent culling of vaccinated animals or vaccination where the vaccinated animals are not culled. However, the latter will in most cases require the ability to distinguish between vaccinated and infected animals both to identify potential carriers, and to regain status as free from disease (Paton *et al.*, 2006; Pasick, 2004). Livestock movement restrictions can be implemented as total standstills on national level, or only in zones surrounding a confirmed outbreak (Anonymous, 2003). Tracing is another essential part of eradication, both to identify the source of infection, and to identify farms to which the infection might have spread. For this purpose the animal movement databases can be of help. However, since there is a delay between movement and reporting, interviews with farmers are essential to capture animal movements that have not yet been reported or registered, as well as other contacts through persons, vehicles and equipment.

It is important to analyse epidemiological data to follow the development of an outbreak and to assess the effect of the intervention strategies (Honhold *et al.*, 2003). In doing such work, modelling can be one of the tools used. However, during the 2001 FMD outbreak in the UK, a conflict developed between expert groups working operatively with the eradication and expert groups of theoretical modellers. Policy makers chose to base the intervention strategies on the outcome of models that were not validated beforehand, and a long debate followed whether or not the strategies chosen were correct or not. (Tildesley *et al.*, 2009; Tildesley *et al.*, 2008; Kitching *et al.*, 2006; Kitching, 2004) Subsequently, the need for close collaboration between the different disciplines has been emphasized, as well as the utmost importance of communicating to policy makers what models can be used for and what their limitations are (Guitian & Pfeiffer, 2006; Crispin, 2005).

An absolute prerequisite for eradication is legislation giving the responsible body the access to farms, sampling, and the right to enforce the necessary measures (Vallat, 2009). Moreover obligations to follow the regulations and also penalties related to non-compliance can be necessary for compliance. Furthermore, economic compensation to farmers is important as an incentive to report suspect disease outbreaks (Vallat, 2009).

1.2.8 Early detection

The period from introduction of a contagious livestock disease into a population until detection of the outbreak is critical since this is the period when silent spread can occur. The more spread, the more difficult the outbreak will be to eradicate. For FMD in the in 2001 and CSF in 1997-1998 it was assessed that up to 79 (Mansley et al., 2003) and 39 (Stegeman et al., 2000) farms respectively were already infected at the time when the first case was diagnosed. Early detection will shorten the silent spread period and is thus important for minimizing the size of an outbreak. One part in early detection is based on farmers and veterinarians reporting suspicion of outbreaks. The awareness among farmers and veterinarians of the symptoms of the relevant diseases and the obligation to report suspicion of disease are therefore essential. However, lack of knowledge is not the only constraint. Recent research has identified social barriers for reporting. The importance of farmers having trust in the authorities and the potential economic consequence for affected farmers has also been identified as highly influential for reporting (Palmer *et al.*, 2009 ; Elbers *et al.*, 2009; Palmer *et al.*, 2009; Vallat, 2009; Hopp *et al.*, 2007).

Another part of early detection can be active screening for specific diseases, most often based on sampling. This can be especially useful for detecting diseases with weak and unspecific symptoms. Sampling can be performed in many different ways, where slaughterhouse- and bulk milk sampling are among the more cost-efficient. At international level, the international systems for reporting disease occurrence can contribute to early detection through increased alertness, e.g if disease is reported by neighbouring countries or trading partners.

1.2.9 Preparedness and contingency planning

Preparedness includes all of the areas related to disease eradication. Several different guidelines for contingency plans exist (Anonymous, 2003; Geering & Lubroth, 2002). One central part is the diagnostic preparedness and plans for facilities and personnel for the field work. However, equally important is the preparedness related to knowledge about the population of susceptible animals, including strengths and weaknesses of relevant animal databases and how these data can be used during an outbreak. Knowledge of the population of farmers is also important; what behaviour do they have related to on-farm biosecurity and movements of animals, and how can they be reached with information. Furthermore, disease spread models to explore potential spread and effect of interventions as a part of decision support can be developed, validated and communicated to policymakers, before an outbreak, so as to try to avoid the type of conflicts that occurred in the UK in 2001 (Guitian & Pfeiffer, 2006).

1.2.10 Post-outbreak and ensuring freedom from disease

In the final phase of an outbreak it is important to ensure that the disease has been successfully eradicated, both to be able to end intervention measures and to reassure international trading partners. Depending on the disease this can be done through clinical surveillance or sampling, or a combination of both. Sampling to support freedom from disease is focused on maximizing the probability of detecting the disease if present (Cannon, 2009; Cannon, 2002). Risk-based sampling can then be a relevant approach, and 'having many live animal contacts' can be one risk-factor to include in the design of the sampling. Other activities post-outbreak are to perform a debriefing and to work through the different aspects of eradication to see if there are lessons to be learnt for the future.

1.3 The Swedish livestock populations and the contagious livestock disease situation

1.3.1 Livestock in Sweden and registration of movements

Currently, there are approximately 23000 agricultural enterprises with cattle, out of which 6500 have cattle for dairy production. Furthermore there are 2400 enterprises with pigs. The pig industry has a pyramidal structure with transports predominantly going downward in the system; from nucleus herds to multiplying herds, from multiplying herds to farrow–to-grower herds and farrow-to-finish herds, and finally from farrow-to-grower herds to fattening herds. An exception from this pattern is the sow pool system. In this system the sows are covered in the central unit, and they farrow in the satellite herds. The sows are regularly moved back and forth between these units. Further, there are 8200 enterprises with sheep and a small and unknown number of enterprises with goats (approximately 5000 goats in total in the country). For both cattle and pigs, there is a trend towards fewer enterprises and larger herd sizes, whereas most of the sheep production is on a small scale level. (Jordbruksverket, 2009c) Livestock production in Sweden is concentrated to the southern parts of the country. All holdings with cattle, pigs, sheep or goats must be registered by Jordbruksverket (the Swedish Board of Agriculture, SJV). The information registered differ between species due to different legislative background, e.g. pig farmers must report the geographical coordinates of the holdings, while this is not a requirement for holdings with cattle (approximate coordinates based on land use are used instead). All cattle are identified (and ear tagged) with unique numbers and all events, such as birth, movements and death shall be reported to the SJV on individual level(Jordbruksverket, 2009a). For pigs, movements are reported on group level (Jordbruksverket, 2009b).

1.3.2 Contagious diseases in Swedish livestock

The geographic location of Sweden is beneficial from a disease spread perspective, being part of a peninsula with no land borders to central Europe, where livestock disease pressure has often been higher. Furthermore, compared to many other countries in Europe, the density of farms is low (but with large regional differences)(Eurostat) and live animal markets are rare (Jordbruksverket, 2003). Moreover, the level of live animal imports is low, and in addition to the official import regulations, the livestock industry has voluntary additional health requirements for imports (SDS, 2009). Furthermore, there is a long tradition of control of livestock diseases in collaboration between the co-operatively owned farming industry, through their animal health organisations and the veterinary authorities. One example is the control of tuberculosis in cattle, which from 1897 was based on identifying infected animals by using tuberculin testing, and separating infected animals from non-infected animals according to the theories of the Danish veterinary bacteriologist Bang. Already by that time the movements of livestock were considered important in relation to disease spread (Anonymous, 1920):

> ...och det genom nutidens bekväma kommunikationer underlättade utbytet af kreatur mellan olika trakter ha äfven i väsentlig grad bidragit till sjukdomens spridning…

> …and the movements of cattle between different regions, facilitated by the present comfortable means of transport, have substantially contributed to the spread of the disease…

Furthermore, as a consequence of a large outbreak of human salmonellosis in 1953, a salmonella control programme with eradication at farm level was started (SVA, 2009). Giving examples from 'modern' times, Sweden started a control programme for bovine viral diarrhoea without vaccination already in 1993 and is now close to free status (SVA, 2009; Lindberg *et al.*, 2006). Furthermore, Sweden is through control programmes free from bovine tuberculosis, infectious bovine rhinotracheitis, enzootic bovine leukosis, bovine brucellosis and Aujezky's disease (SVA, 2009). However, history does not protect from disease introduction and in recent years both Bluetongue and Porcine Respiratory Reproductive Syndrome (PRRS, now eradicated) have been introduced into Sweden (Sternberg Lewerin *et al.*, Accepted; Carlsson *et al.*, 2009) and there is a need for a scientific basis for preparedness and decisions in matters related to prevention and eradication. Such a basis includes valid data describing on-going processes in the animal population that affect the spread as well as the control of infectious diseases.

2 Aims

The overall objective of this project was to investigate contacts between Swedish holdings with cloven hoofed livestock, with implication for the spread of contagious diseases and with focus on animal movements and on-farm biosecurity. The work is part of a joint project with the long term goal of producing models for exploring disease spread and control.

More specifically the aims were:

- To investigate geographical and temporal aspects of the Swedish cattle and pig populations, in particular; 1) reported movements of pigs and cattle 2) reported births and deaths of cattle and 3) geographical location of holdings.
- To estimate network analysis measures that may be useful for disease control and surveillance from data on movements of Swedish cattle and pigs and to investigate associations between the measure infection chain and herd characteristics.
- To investigate on-farm biosecurity routines on Swedish farms with cattle, pigs, sheep and goats through questionnaires directed to farmers in different parts of the country and to examine if there were differences related to species, geographic region and herd size.
- To investigate Swedish pig farmers' disease awareness, information retrieval and if they change their biosecurity routines during an outbreak of an exotic infectious disease, using the experience from the first outbreak of PRRS in Sweden in 2007.

3 Methodological considerations

This thesis is based on four separate studies, where I and II are studies of reported movements of live cattle and pigs, and III and IV focus on on-farm biosecurity and disease awareness. The two latter were based on data collected through questionnaires to Swedish farmers with cattle, pigs, sheep/goats (Paper III) and farmers with pigs (Paper IV). This section gives a general overview of the material and methods used; detailed descriptions are given in each paper I-IV.

3.1 Study populations

For all studies, the holdings and farmers were included or selected using information from the databases of SJV. The study populations for each paper were:

- Paper I: All registered pig and cattle holdings[1] in Sweden, that were involved in reported animal events (e.g. movements, births), during the period 1st of July 2005- 30th of June 2006
- Paper II: All registered pig and cattle holdings in Sweden, that were involved in reported animal events (e.g. movements, births), during the period 1st of January 2006 – 31st of December 2008.
- Paper III: Random sample of farmers (person registered as responsible for holding), stratified based on species (cattle, pigs, sheep, goats; as stated in the holding register), geographic location and type of production registered (pigs only). In addition a non-random sample of large cattle herds was added to the study population. In total 1498 farmers.

[1] Holding ('produktionsplats' in Swedish) in the SJV databases includes farms, pastures, slaughterhouses, vehicles or other places where live cattle, pigs, sheep or goats are gathered. In these studies, slaughterhouses were excluded from the analysis.

- Paper IV: Responders to the questionnaire in study III that at the time of selection for study IV were identified as having reported pigs to be present on the holding in the questionnaire for study III. In total 153 farmers.

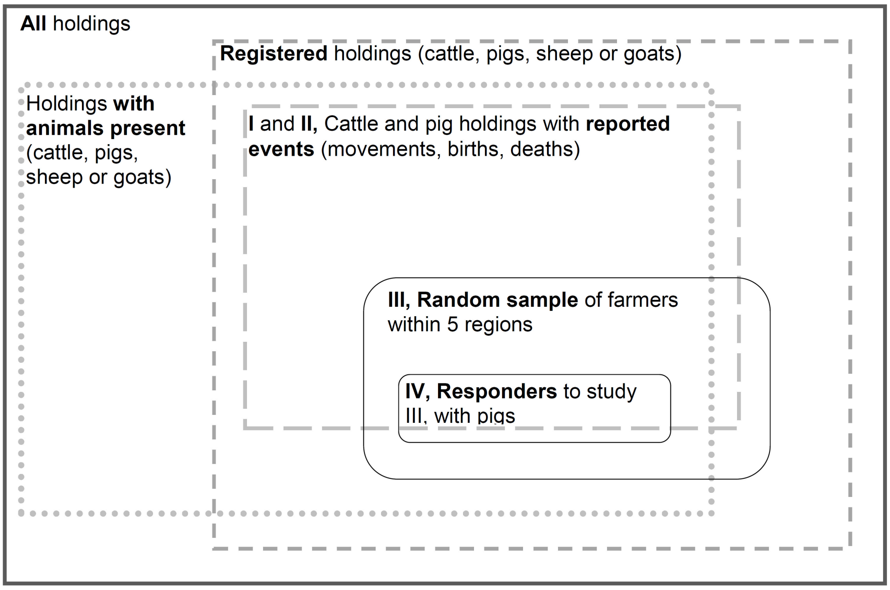

Figure 2. Holdings and study populations in studies I-IV (the sizes of the boxes are not proportional to the actual number of holdings in the different groups).

3.2 Cattle and pig movements

3.2.1 Data

Data on all reported movements of cattle and pigs during the time periods 1st of July 2005 - 30th of June 2006 (Paper I), and 1st of January 2006 – 31st of December 2008 (Paper II) were obtained from SJV. Moreover data on the cattle reported present on each holding at the starts and the ends of these periods were obtained.

3.2.2 Geographical and seasonal structures of movements

The overall geographical structure of the movements was examined (Paper I). This was done through analyzing the distance of the movements by using Euclidean distance (or in everyday language "as the crow flies") based on the data available in the SJV databases; i.e. geographical coordinates for pig holdings and approximations of geographical coordinates for cattle holdings. Furthermore the proportions of movements within counties, and to adjacent counties, were investigated (for county borders see Paper I, Figure 1). The reason for using county level was that regionalisation within the EU directives for eradication of e.g. FMD is suggested to be based on administrative regions (Anonymous, 2003). Moreover the frequency of movements between the three larger geographical regions (Götaland, Svealand, Norrland) was investigated to assess the North-South movements in the country. Seasonal variations in animal movements were examined using weekly intervals. The reason for this was that seasonal variation has been observed in other countries (Robinson & Christley, 2006) and occurrence of seasonal variation could affect future studies based on animal movement data, if not full year data are included.

3.2.3 Network analysis

The contact structure was examined using network analysis (Paper II), a method that explores relations between 'actors' or 'nodes' (e.g. livestock holdings) and how they are connected or linked (e.g. trough movements of livestock). The links can be analysed either as directed or undirected, and furthermore the sequence in which the links occur can be included. Both the direction and the sequence in which contact occur are of vital importance for potential disease spread; a movement from holding A to holding B can spread disease from A to B, however, not from B to A. The movement data of cattle and pigs contain the information needed for analysing directed networks where the sequence of the movements are taken into account: the starting point (the holding from which the animal is moved), the end point (the holding to which the animal is moved), the direction of the movements, as well as the time when the movement occurred.

The network measures estimated were measures of the general structure of the network; CLUSTERING COEFFICIENT, DEGREE ASSORTATIVITY, DENSITY, FRAGMENTATION, and GROUP BETWEENNESS CENTRALISATION INDEX (Borgatti, 2003; Newman, 2002; Watts & Strogatz, 1998). These can be used as a basis when generating networks for modelling disease spread, which is one way to avoid assumptions of homogenous probability for contacts between different holdings in disease spread models (Keeling & Eames, 2005).

Further, measures that have been described and discussed in relation to disease control and estimates of epidemic sizes were estimated. The measure DEGREE captures the movements to and from a specific holding and can be divided into IN-DEGREE and OUT-DEGREE (see paper II, Figure 1) (Dubé *et al.*, 2009; Martinez-Lopez *et al.*, 2009; Christley *et al.*, 2005a; Christley *et al.*, 2005b; Wasserman *et al.*, 1994). Strong and weak components were also identified. A strong component is a part of the network where all holdings can reach each other through directed links, either directly or via other holdings, and the GIANT STRONG COMPONENT (GSC), is the largest strong component in the network. Further, a weak component is a part of a network where all holding are in contact with each other either directly or via other holdings, not taking the direction of the contact into account. The GIANT WEAK COMPONENT, (GWC), is the largest weak component in the network (Kao et al., 2006). The GSC and the GWC have been proposed as estimates of maximum epidemic size (Kao et al., 2006), however the sequences of the movement are not taken into account, as discussed by Dubé and co-workers (Dubé *et al.*, 2009; Dubé *et al.*, 2008). In contrast, the sequence of the movements is taken into account in the OUTGOING INFECTION CHAIN, which is a measure of the number of holdings in contact with a holding through animals leaving the holding. The measure captures contacts both through direct movements, as well as indirect contact through further movements (see paper II, Figure 1) (Dubé *et al.*, 2008; Webb, 2006).

Inspired by the work of Webb, Dubé and co-workers, the INGOING INFECTION CHAIN was constructed and described in this work (paper II). The ingoing infection chain measures all direct and indirect contacts through movements onto a holding. Just like the outgoing infection chain, the sequence by which the movements occur is taken into account (see paper II, Figure 1). This measure can be useful in risk-based design and evaluation of surveillance systems (Cannon, 2009; Martin *et al.*, 2007), or e.g. to include as a potential risk factor in analysis of endemic disease occurrence.

As a final step in the analysis of the movement data, associations between herd size, production type, region and the measures INGOING INFECTION CHAIN and OUTGOING INFECTION CHAIN were investigated (explained further below, section 3.4).

3.3 Data collection through questionnaires

For the study on biosecurity (paper III), the aim was to investigate general levels of on-farm biosecurity, and if there were differences related to species kept on farm, production type or geography. The latter was of interest since there are regional differences in farm density, and it was assumed that this, in combination with regional 'norms', may affect biosecurity routines. It was chosen to use written questionnaires distributed through regular mail for data collection. This choice was based on a combination of the study population aimed for, and available time and funds. The alternatives to collect the data from the farms through farm visits and interviews, or to pay field veterinarians to collect the data from the farmers or to do a web-based questionnaire were not deemed feasible. Furthermore, the number of farmers selected was a compromise between the factors having enough data to analyse, expected non-response, time limitations for data entry and number of holdings in the counties.

There are both advantages and disadvantages with questionnaires posted by mail. Advantages are that they are cheap and that a large number of farmers in different geographical areas can be reached, which was the major reason for the choice. Further advantages are that written questionnaires can be treated anonymously and farmers may feel more comfortable reporting what their routines actually are instead of what they believe to be the 'correct answer' in contrast to the situation during face to face interviews. However, the reported routines cannot be checked, which would be possible during a farm visit, and that is a disadvantage. Furthermore, there is no possibility to ensure that all questions are answered, to ask follow-up questions or to explain questions that the respondent perceives as unclear. (Dohoo *et al.*, 2009) Although common vocabulary was used and the questionnaires were tested on farmers, it was clear from responses that some farmers, in particular those with 'hobby herds' were not always familiar with the nomenclature.

The overall response rate was 34%, and this was examined further through investigating potential associations between RESPONDING TO THE QUESTIONNAIRE, SPECIES REGISTERED ON THE FARM and GEOGRAPHICAL REGION (data used for selecting farms for the study). The only significant difference was a higher response rate within the stratum REGISTERED PRESENCE OF SHEEP AND GOATS ON THE FARM as compared to other farmers. It would have been interesting to investigate the response using variables related to the individual farmers (e.g. age, gender, educational level); however such data were not available. Farmers not wanting to participate were asked to state their reason for not participating and 32% gave their reason for this. The main reason (50%) was DO NO LONGER HAVE LIVESTOCK ON HOLDING, i.e. these farmers were in fact not part of the study population.

Non-response can be a source of bias if the non-responders differ from the responders. One factor that can cause bias is that persons with special interest in the topic of the questionnaire may be keener to respond. From the wide variety of routines reported, it is not probable that only farmers with special interest in biosecurity responded, even though they may be overrepresented. An alternative way to gather data on on-farm biosecurity, which is not depending on the farmers' willingness to participate in questionnaires studies, is to use another source of information, such as professionals visiting farms, and ask them about the frequency of biosecurity routines among different types of farmers. A plan for such a study exists, however due to the outbreak of PRRS in 2007 a study of farmers' disease awareness and information retrieval in relation to an outbreak was prioritised (paper IV).

For the disease awareness study (paper IV), responders to the biosecurity questionnaire that had reported that they had pigs on the farm were contacted. Unfortunately some were missed at the time of selection, and that is the reason for the difference in the number of pig farmers in papers III and IV. The reason for selecting only pig farmers was because PRRS only affects pigs. Also for this study, questionnaires distributed through regular mail were used for data collection and the reasons were the same as above; available time and money. The response rate for the second study was 95%. This can be explained by the fact that all pig farmers contacted were responders from the biosecurity study and consequently they were were good at responding to questionnaires. The questions to the farmers about awareness of the symptoms of PRRS and how to prevent introduction of PRRS to their farm were based on self-assessment without any questions validating their knowledge. This can both have overestimated and underestimated what they actually knew.

The information collected (paper III and IV) were entered into a Microsoft Access database using forms with the same design as the questionnaires. Due to time constraints, single entry of the responses was used, although double would have been preferred in order to reduce the risk of errors in data entry (Dohoo *et al.*, 2009).

3.4 Data editing and testing of associations

In Papers II-IV potential associations between farm characteristics (herd size, type of production, species and region) and outcomes related to movement patterns (INGOING INFECTION CHAIN and OUTGOING INFECTION CHAIN), biosecurity routines, disease awareness and information retrieval were assessed. Limitations in the covariates related to farm characteristics are discussed further below (3.6).

For the INGOING INFECTION CHAIN and OUTGOING INFECTION CHAIN (Paper II) it was decided to investigate potential differences between holdings with highest yearly INGOING INFECTION CHAIN and highest yearly OUTGOING INFECTION CHAIN respectively, and the other holdings. Therefore the data was dichotomised and the cut-off was set at the 90th percentile. Our main objective was to investigate if farm characteristics were indicative of many indirect contacts. The method used to estimate the magnitude of potential associations was logistic regression. The motive for choosing this method was that it is an established and robust method to investigate associations with bivariate outcomes, accounting for more than one covariate.

In the questionnaire data (Paper III and IV), many of the responses were of the type 'yes' or 'no', i.e. already dichotomised. For some of the questions, the farmers had been given intermediate alternatives, such as 'almost always' or 'sometimes', between e.g. 'always' or 'never'. The reason for this was to give the farmers alternatives if they in fact did have variation in their routines. The intermediate alternatives were included in the descriptive statistics; however, for the further analysis of associations they were dichotomised, and merged with either of the extremes closest in meaning. The responses to the questions in the biosecurity questionnaire (Paper III) were first investigated using multiple correspondence analysis. This is a method used to explore and visualise relations between multiple categorical variables in a dataset without apparent causal relationship (Dohoo *et al.*, 2009). The method has been used by other authors to investigate on-farm biosecurity routines (Costard *et al.*, 2009; Ribbens *et al.*, 2008). Further, potential associations with farm characteristics were analysed using logistic regression in both paper III and IV.

3.5 Investigations related to quality of data in the SJV databases

To assess the validity of data in the databases of the SJV was not one of the primary aims of this project. However, in the different studies some assessments related to data quality were done.

In Sweden, movements of cattle are reported both by the seller and the buyer and therefore, reports were matched (to avoid counting the same movement twice) (paper I and II). A stepwise process was used to identify matching reports and reports without a match. A comparison of the number of reports that could not be matched was done for the three-year period 2006-2008 (paper II).

During the study period for the animal movements (paper II), reporting routines were changed. From April 2007 the vehicle should be included in reported movements when animals of different origin, and destined for more than one holding, are mixed on the same vehicle (the reason for this is that disease can potentially be transmitted during the transport). Such reports were identified in time and quantified (paper II). Furthermore the number of pigs reported to enter a vehicle was compared to the number of pigs reported as leaving the same vehicle.

Reported births and deaths were investigated in relation to day of the week and day of the month (paper I). Reported numbers were compared with expected numbers, assuming equal distribution among the days.

Holdings lacking information on geographical location were excluded from analysis of the distance of the movements as well as analysis of the number of holdings within 3 and 10 km radiuses from each holding (paper I).

In analyses of movements (paper I and II), only holdings involved in a reported event were included, based on the assumption that zero reported events indicated that there were no animals on the holding. Theoretically this excluded holdings that had animals present but no births, deaths or movements of these (or that failed to report events). However including all holdings in the register would have overestimated the number of holdings.

For the selection of farmers for the questionnaire on biosecurity (paper III) holdings that had been registered as 'no longer active' were excluded. However, in order to investigate potential over-coverage the question 'do no longer have livestock on holding' was included when farmers not wanting to participate in the study were asked to give the reason why. Moreover, the reported presence of the species for which the farmer had been selected was compared to the species reported in the questionnaire response to be present (paper III).

3.6 Herd size, type of production and species

In papers II and IV TYPE OF PRODUCTION and HERD SIZE were included as potential covariates in the models, and in paper III HERD SIZE and SPECIES were included. The approach was to use what was thought to be the best data available for these covariates, with the consequence that the covariates were not the same in the different studies. Information reported by the farmers when responding to the questionnaires was assumed to be more reliable than information in the registers of the SJV, and used when available, i.e. in paper III and IV. The reasons for this were the constraints in the SJV databases. Examples of such constraints are that for cattle, the production type is not registered and for pigs, a maximum of two different production types are registered based on the information given by the farmer at the time of first registration. However, no definitions are given and the interpretation of production types can be assumed to be arbitrary.

Further, when comparing registered type of production with registered number of places for sows or pigs for slaughter, these did not always correspond well, e.g. there were holdings reported as fattening with no places for fattening pigs.

In the network analysis study of cattle and pig movements (paper II), the registered type of pig production was used, and based on the breeding pyramid the highest level of production was set as TYPE OF PRODUCTION, e.g. if both multiplier and fattening was registered, multiplier was used. For cattle, data from The Swedish Dairy Association on holdings delivering milk were combined with reported births. Holdings registered as delivering milk were categorised as dairy herds, holdings not delivering milk in combination with reported births were categorised as suckler herds, the rest as fattening herds. Further, the number of cattle on the holding the 31st of December 2008, i.e. the last date of the study period was used. For pigs the number of registered maximum places in the stables for sows and fattening pigs were used. The HERD SIZE was divided into three groups; small/hobby, medium and large and the categorisation of farms were based on quartiles. Only holdings involved in a reported event related to the species in question were included in the analysis.

Due to the constraints in the register data, holdings may have been misclassified both related to HERD SIZE and TYPE OF PRODUCTION. Non-differential misclassification reduces the strength of associations, and differential misclassification can either strengthen or weaken the associations (Dohoo *et al.*, 2009). One type of misclassification was due to the approach for identifying TYPE OF PRODUCTION based on milk-production and births which incorrectly classified holdings with only heifers as fattening herds. Even though these covariate data had limitations, they were assumed to be of sufficient quality for use in the models.

In paper IV, production type was based on what the farmer had reported when responding to the questionnaires. Due to the arbitrary interpretations of production type by farmers with small herds, a TYPE OF PRODUCTION called 'hobby' was created, this to avoid reducing the strengths of associations due to misclassification. The species reported by the farmer to be present on the farm was used in paper III. In both paper III and IV, the numbers of animals reported by the farmers in the questionnaire replies were used. However, sows and fattening pigs were not separated in the biosecurity questionnaire, whereas they were separated in the disease awareness study. The HERD SIZE was divided into three groups; small/hobby, medium and large and the limits for size categories were set including rough assumptions of the farm intensity. Misclassification may have occurred in these studies as well, even though they were based on farmer reporting.

4 Main results

4.1 Animal movements

The majority of the cattle and pig movements were within 100 km from the herd of origin (paper I). However, 5% of the cattle movements and 9% of the pig movements were to holdings more than 200 km away, up to 1200 km for cattle and 1000 km for pigs. The occurrence of these long distance movements can have consequences for spread of disease. There was a skewed distribution of contact frequency with approximately 50% of the holdings not having any registered ingoing movements. Many had only a few ingoing movements, and a small number of holdings had many (paper I and II). There was a seasonal variation in movements of cattle with peaks in spring and autumn (paper I and II).

The measures of direct (IN-DEGREE and OUT-DEGREE) and indirect (INGOING INFECTION CHAIN and OUTGOING INFECTION CHAIN) contacts were not equal; some holdings with only a few direct contacts had many indirect contacts (Paper II). Although there were constraints in the data describing herd size and production type (see section 3.6), the associations found in movement patterns were largely as expected from what can be assumed from the different types of production; fattening herds (both cattle and pigs) and sow pool holdings were significantly associated with a high INGOING INFECTION CHAIN. Dairy holdings, pig nucleus and multiplier holdings, as well as sow pool holdings were significantly associated with a high OUTGOING INFECTION CHAIN (Paper II).

4.2 Biosecurity

There was a large variation in reported on-farm biosecurity, with differences both between and within different types of farms (paper III). For example, less than 40% of the farmers reported that they provided protective clothing for farm visitors and 50% of farmers buying animals introduced them directly into the herd without prior isolation. However, only ten percent of the farmers characterised their routines as insufficient. In general, pig farming was associated with higher biosecurity routines related to protective clothing and farm visits, and lower biosecurity was associated with having cattle, sheep/goats, or mixed species. A low level of biosecurity was also associated with hobby farming. Inconsistent routines were reported, which was interpreted as a lack of knowledge of how infectious diseases spread and how these routes of spread can be controlled. In relation to the PRRS outbreak, one fourth reported that they had changed their routines and out of them two thirds still had the new routines in place six months later (Paper IV). Moreover, the reported usage of protective clothing differed both within and between different groups of professionals (Paper III). Veterinarians and AI-technicians were reported to have the best usage of protective clothing, whereas animal transporters and salesmen were reported to have a poor usage. Animal transporters were further reported to quite frequently enter the stables (although less commonly in pig farms), whereas carcass collectors were reported not to enter the stables.

4.3 Disease awareness and information retrieval

Ten percent of farmers in the study reported that they were not aware that there had been an outbreak of PRRS (Paper IV). However, it is known that written information had been sent to them, and there had been frequent reporting of the outbreak in the media. Awareness was strongly associated with herd size; farmers with small herds were less aware of the disease. Forty percent of the farmers reported that they had actively searched for information during the outbreak, and out of these more than 50% used the Internet to find information. Information search was significantly associated with herd size and geographic location, with higher odds for information search for farmers with larger herds and in the region where the outbreak occurred. The Swedish Animal Health Service (SvDHV) was reported by more than half of the responders as the most important and reliable source of information, and this was significantly related to herd size, with higher odds for larger herds. The second most reliable source of information was the veterinary authorities (The Swedish Board of Agriculture and the National Veterinary Institute).

Written comments made by some of the responders in the biosecurity study (Paper III) indicated a low perceived risk of disease introduction, and the expectation that they would be informed about outbreaks in time to improve biosecurity. Further comments indicated that not all farmers were aware of the endemic occurrence of e.g. FMD in many parts of the world.

4.4 Databases and data quality

From the investigation of reasons why farmers declined from participation in the biosecurity study (paper III) it was revealed that many farmers did not have any livestock on the holding, indicating errors in the information in the holding register. Out of approximately three hundred farmers giving their reason for non-response, 50% of them did not keep livestock on the holding any longer. The species for which the holdings had been selected were reported to be present on eighty percent of the farms (paper III). For the cattle movement reports, there seemed to be an improvement over time with fewer non-matching reports in 2008 compared to 2006 (paper II). Reporting of vehicles, on which animals had been mixed during transport, did not start directly when the new reporting routines came into force, and this indicates that transports and farmers might not have been aware of the changed reporting requirements. Furthermore the number of animals entering the vehicle did not always correspond to the number of animals leaving the same vehicle (paper II). Eleven percent of the active cattle holdings and 2% of the pig holdings were excluded from the analyses of distance of movements, since they did not have any approximate coordinate data or coordinate data (Paper I). The 1st, 10th, 15th and 20th in each month were frequently reported days for cattle deaths, and for births as well. However, it is unlikely that there was a true clustering of births and deaths on these dates, and the probable reason is recall bias and digit preference in the reporting (Paper I). Digit preference is a well known phenomenon, where there is a tendency to choose certain numbers, e.g. even numbers or numbers ending with five, when the exact number is not known (Bopp & Faeh, 2008; Broad *et al.*, 2007; Miller & Anderson, 2002). Digit preference has also been described in the UK cattle databases (Robinson & Christley, 2006).

5 Discussion

Livestock movements and deficiencies in on-farm biosecurity and disease awareness affect spread of disease. In case of introduction of an exotic disease, these factors affect the amount of silent spread before detection which can have consequences for the size of an outbreak. From the results of this study it is clear that many farmers and professionals visiting farms do not apply routines sufficient to prevent the spread of disease and that some farmers missed information about ongoing outbreaks, or had low disease awareness in general. Furthermore, there were movements of animals over long distances, with the consequence that an outbreak could potentially have spread over large geographical areas at the time of detection. Having said this, and without ignoring the need for improvement, there were also the good examples of farmers applying high biosecurity and farmers with high disease awareness, and further, many farmers had closed herds without introduction of live animals. Moreover, there are circumstances in Sweden that provide a good starting point for the prevention of disease spread. These are, for example, the relatively low farm density compared to many other countries (Eurostat), hardly any live animal markets, a long tradition of disease control, a strong farmers' union, tradition of collaboration between the farming industry and the veterinary authorities, and reported trust in information from the veterinary authorities.

5.1 Patterns of livestock movements

The patterns of livestock movements are relevant in the acute phase of an outbreak when deciding if a total standstill of movements is necessary, and if so, in what parts of the country the standstill should be implemented. The findings of the long distance movements, through the analyses based on geographic location of the holdings, support the implementation of a total standstill in the whole country until detailed contact tracing has been done. Further, the highly skewed distribution of livestock movements identified that there were a limited number of holdings with many contacts; both holdings that sold animals to many holdings (and thus could be efficient spreaders of disease), and holdings that bought animals from many holdings (with a consequent high risk for disease introduction). For disease spread it is not only the direct contacts that are relevant but also the indirect contacts and these did not always correspond to each other; some holdings with few direct contacts still had many indirect contacts. The measure OUTGOING INFECTION CHAIN includes the indirect contacts and is thus a relevant network measure to identify the potential 'spreaders' (Dubé et al., 2008). The INGOING INFECTION CHAIN, which to our knowledge has not been described by other authors for use on livestock movements, can correspondingly be useful for identifying holdings at high risk for introduction of disease. This can for example be relevant for identifying holdings to include in risk-based screenings early in an outbreak to assess the extent of the outbreak (in addition to sampling based on direct contact tracing). Further, this measure can be used in control programmes for endemic diseases or in the design or evaluation of surveillance programmes or early detection systems of exotic diseases or for documenting freedom from disease. Risk-based surveillance is an expanding area within veterinary epidemiology with relevance for e.g. guarantees related to international trade (Martin *et al.*, 2007; Cannon, 2002). Targeted sampling in high risk herds can for these specific purposes be more cost effective than random sampling (Cannon, 2009). Attempts made to compare the Swedish networks with results from other countries were not straightforward, due to different populations included and different time periods. However, comparisons with results from the UK (Robinson *et al.*, 2007; Christley *et al.*, 2005b) indicate that the Swedish cattle population was less connected. This is probably due to less trade among Swedish cattle farmers and due to the fact that animal markets, which are common in the UK, are rare in Sweden (Robinson & Christley, 2007; Jordbruksverket, 2003).

5.2 Biosecurity

A large variation in on-farm biosecurity was found, with variation both within and between different categories of farms. Although pig farmers generally had higher on-farm biosecurity compared to farmers with cattle, sheep/goats or mixed species, many farmers had biosecurity routines that were not satisfactory from a disease prevention perspective. Furthermore, the inconsistent routines reported, (for example isolation of animals before introduction into the herd, but using the same equipment and clothing as in the rest of the herd) were interpreted as a lack of knowledge of how diseases spread, and in what way the biosecurity measures are supposed to break the different routes of transmission. These apparently inconsistent routines also highlighted the importance of asking the farmers in detail what their actual routines are when conducting disease-tracing interviews. For example, it cannot be assumed that animals kept in 'on-farm quarantine' are actually isolated from the rest of the herd.

From the findings it is concluded that improvement of the on-farm biosecurity is needed and the subsequent question is; how can this be achieved? If more information to farmers was the solution, better results would have been expected, considering all information campaigns from the industry and the veterinary authorities during the years. Although knowledge is a prerequisite, knowledge is not always sufficient to change behaviour. Recent research in Australia shows that farmers can be well informed about biosecurity, and nevertheless fail to apply the routines they have knowledge of (ref Palmer). For a comparison with the human health side; it is seldom lack of knowledge of the risks associated with smoking that prevents smokers from breaking this habit, or lack of knowledge that unprotected intercourse can lead to unplanned pregnancy or sexually transmitted infections that is the reason for not using condoms (Ekstrand, 2008; Stewart & Rosser, 1982). Achieving changes in behaviour is much more complex than just providing information. Within social science and human health research, models are used to identify motivators and barriers for certain behaviours, such as e.g. Theory of Planned Behaviour, Theory of Reasoned Action and Health Belief Models. In short, these models aim to identify factors affecting the final behaviour such as beliefs, intentions, social norms, perceived consequences, perceived susceptibility, actual and perceived constraints. They also aim to identify people or sources of information whose opinions have impact on the persons' actions. This type of research is just beginning to be used within veterinary epidemiology (Ellis-Iversen *et al.*, 2010; Gunn *et al.*, 2008; Heffernan *et al.*, 2008; Garforth *et al.*, 2006). Traditionally veterinary epidemiologists have investigated factors with which we are familiar and that are easily measured such as species and type of production, and largely ignored these other factors which actually are the ones that will affect farmers' behaviour. In order to move forward with improving on-farm biosecurity in Sweden, there is a need to identify different barriers and motivators as experienced by the Swedish farmers and use these as a basis for future work. In relation to this, the 'good examples' identified through this study should be examined along with investigations of which parts of the previous work to improve biosecurity have been successful and why. As mentioned, it was clear that the pig producers (with only pigs on the farm) had higher reported biosecurity compared to other farmers. It can be hypothesised that either the strict biosecurity routines related to the eradication programme for Aujeszky's disease in the 1990-ies were still remembered, or that the continuous work of the Swedish Animal Health Service (SvDHV) has been successful, and this is worth examining in more depth. On the professional side the 'role models' for use of protective clothing were the veterinarians and AI-technicians which may not be a surprise. However, one category that instead of protective clothing had the routines of not entering the stables was the carcass collectors. It would be interesting to investigate how their organisation has managed to enforce these routines among farmers. If the carcass collectors have been successful, a behavioural change related to not letting animal transporters enter the stables seems possible. This would be needed due to their reported poor usage of protective clothing combined with often entering the stables.

5.3 Risk perception and disease awareness

In motivating a behavioural change the perceived risk is of interest (Palmer *et al.*, 2009 ; Palmer *et al.*, 2009; Ekstrand, 2008). From the biosecurity study (paper III) it was clear through the comments that some farmers perceived the risk of introduction of disease as low, and that the period of silent spread was not considered, such as;

> Our routines are sufficient for now when the disease pressure is low.
>
> Our routines are altered when we are informed through the media about ongoing outbreaks.

From the PRRS outbreak the experience was that farmers located close to the outbreak were more active in searching for information. Other studies have also shown that closeness to outbreaks increased the concern among farmers (Brook & McLachlan, 2006). Furthermore, two thirds of the farmers that improved their biosecurity routines during the PRRS outbreak still had the stricter routines in place six months later, maybe as a consequence of a changed perception of the risk of disease introduction. Another recent observation made through interviews with advisors from the construction industry, is that Swedish farmers in areas with higher apparent prevalence of salmonella more often asked biosecurity-related questions when planning new stables (Bengtsson, 2010). Although the extent has not been assessed, the interpretation of these findings is that perceived risk of disease introduction seems to have an effect on biosecurity awareness among Swedish farmers. Referring to the section on preventive work in the introduction (section 1.2.6), and the 'known' and 'unknown' threats; it is clearly a difficult task to communicate the risk of the 'unknown' threats. The message will be something in line with: 'Be prepared, always protect your farm from outbreaks of unknown disease that may never occur'. However, to achieve an efficient on-farm biosecurity able to prevent silent spread, conveying this message will be necessary. McNab and Dubé discuss this problem and suggest illustrative models as tools in communicating the message to the farmers that what they do every day can potentially have impact on the course of an outbreak (2007). Emphasising that high and cost-effective on-farm biosecurity can prevent introduction of endemic diseases might further motivate farmers.

5.4 Communication

In all communication, both in the preventive work related to biosecurity, disease awareness and early notification as well as during outbreaks it is important to get the message through to everyone involved, both farmers and professionals. From the PRRS awareness study it was clear that some farmers (hobby farmers) were not aware of the disease and had missed that there was an outbreak, even though written information had been sent to them and frequent media reporting was seen in relation to the outbreak. This pinpoints the need to identify ways to reach different groups (and personalities) with information, and one way will probably not fit everyone. For example, some hobby farmers did not consider themselves as farmers and may thus not be part of different farming related networks, such as e.g. the SvDHV which otherwise was reported by pig farmers to be an important source of information during the PRRS-outbreak. This finding was strongly associated to herd size, i.e. the SvDHV were important for informing their members, with which they already had an established relation. Further, the disease awareness study revealed that many farmers searched for information on the Internet during the outbreak; consequently, it is important to provide correct and easily accessible information for farmers on the Internet in case of an outbreak. The demand for information for farmers about suspicion and diagnostics of CSF available on the Internet was recently identified in a Dutch study (Elbers et al., 2009). Moreover, behavioural research could help identifying ways to get the messages through; both the ways in which the information should be communicated and by whom the message should be sent. The importance of famers' trust in the messenger related to biosecurity has been identified both in Australia and in the UK (Palmer *et al.*, 2009; Heffernan *et al.*, 2008). An example of successful communication strategies is the approach used during the final phase of the rinderpest eradication programme in Sudan. When vaccination was to be replaced with clinical surveillance and reporting of outbreaks, the communication strategy started by investigating which routes of communication that were normally used within the society. These were applied, and the message was successfully brought forward through storytelling tradition, songs and art (Jones *et al.*, 2002). The approach highlights the need to identify the communication patterns of the groups to be informed and the need to involve experts in communication.

5.5 Live animal trade and risk perception

Returning to the livestock movements (now at the level of the individual farmer), these can also be discussed from a risk perception perspective. Among farmers buying live animals almost half of them reported that they introduced them directly into the herd without prior isolation (although less common among pig farmers) or had insufficient isolation routines to prevent disease spread. These findings indicate that not all farmers perceive live animals as a risk for disease introduction, or at least not a risk serious enough to alter their behaviour. Again, motivators and barriers need to be identified in order to understand the reasons and enable change of behaviour.

Reporting all cattle and pig movements to the SJV databases is an administrative burden to many farmers. Currently farmers only have access to data directly related to their own farm and no information concerning indirect contacts through their trading partners. As a comparison, the Danish register, Centralt Husdyrbrugs Register, is transparent, with open access for anyone to search for information on holdings and animals. Furthermore, information on status regarding some diseases is included in the Danish register (CHR, 2010). It is recognised in the Swedish animal health legislation related to salmonella control that trade with live animals is a risk for introduction of salmonella, and farmers' trading patterns will affect the compensation of eradication costs if their herd would get salmonella (farmers are allowed to buy calves from a maximum of five different holdings without compensation being affected). However, this is only related to direct contacts. From a risk perspective, there is a difference in buying animals from farms that do not buy animals, compared to herds that have many ingoing contacts. From our results it was clear that some farmers with few direct ingoing contacts had a significant number of indirect contacts. The network measures DEGREE and INGOING INFECTION CHAIN would be relevant measures for farmers to have access to, both when assessing their own contact structures and when choosing partners to trade with. Making these measures available to farmers could be helpful in the process of making farmers more aware of the risks with live animal trade.

5.6 Using register data for disease control purposes

One of the primary aims of the livestock movement databases (Anonymous, 2008; Anonymous, 2000b; Anonymous, 2000a) is disease control and it is important that data is continuously made available for work related to disease control and research. In Sweden several research projects have validated veterinary databases (Mörk, 2009; Penell, 2009; Egenvall, 1999), however, the SJV holding and livestock movement databases have not yet been subject to validation in relation to disease control. Validation and continuous usage of data for disease control purposes can enable detection and correction of erroneous data and other constraints. This is necessary for the databases to be useful in an outbreak situation, e.g. if the databases are used for disease modelling or as a basis for control strategies.

Challenges with regard to data quality are to be expected in large databases, and problems similar to the ones reported have also been reported from the UK (Green & Kao, 2007; Robinson & Christley, 2006). Still, the databases are potentially very useful and, furthermore, this project has favourably allowed us to discover some of the weaknesses of the databases in time, and not during an outbreak. A positive finding was that the number of erroneous cattle movement reports decreased during the time period. However, further improvements of the databases would make them even more useful. Suggestions of improvements are to: i) include data on type of production and geographical coordinates for cattle holdings, ii) provide clear definitions for the farmers at time of registration, e.g. definitions of different types of production, iii) on a regular basis update information related to species present, type of production and herd size, e.g. maximum number of pig units, iv) continuously identify and correct erroneous data, e.g. non-matching reports for cattle movements. Errors detected in the databases have been communicated to the Swedish Board of Agriculture.

5.7 Modelling project

As mentioned in the aims, this project is part of a joint project with the long term goal to develop models for disease spread and control. One of the purposes with the joint project is to establish collaboration in ‘peacetime’ between veterinary experts in disease control and mathematical modellers at Linköping University and The Univeristy of Skövde. Work with model development is ongoing. The results of this thesis contribute to the knowledge necessary about the Swedish situation as a basis to parameterise such models, and for comparing networks generated by different algorithms to the real world contacts

6 Concluding remarks

- There were reported movements of live cattle and pigs over large distances (up to 1200 km). Such long distance movements support initial total standstills in the entire country in case of an outbreak of e.g. FMD. While many holdings had few or no contacts through live animal movements, there were a number of farms with many contacts that potentially could play an important role in disease spread.

- The animal holding and movement databases are useful for disease control purposes. However, constraints in the data were discovered (e.g. inactive farms, arbitrary interpretation of production type, non-matching movement reports, missing geographical coordinate data, digit preference in reporting). To be useful tools for disease control, and especially in case of an outbreak, the databases need to be validated and continuously used for disease control purposes.

- The network measures IN-DEGREE, OUT-DEGREE, OUTGOING INFECTION CHAIN and INGOING INFECTION CHAIN can be very useful measures for disease control and risk based surveillance. Furthermore, the measures could be useful for farmers, as a base for choice of trading partners. However, in order to be useful they must be continuously updated. Development of tools to obtain these measures continuously for all holdings is needed.

- Many farms did not have sufficient biosecurity routines to prevent introduction of endemic diseases or prevent silent spread of an outbreak, neither did they have the perception that this would be needed. There was large variation in reported on-farm biosecurity routines and the variation was associated with species present on the farm and herd size.

- There was substantial variation in the usage of protective clothing among professionals visiting farms. Animal transporters were identified as a risk group since they often enter the farms without proper usage of protective clothing.

- There is a need to improve on-farm biosecurity routines, both among farmers and professionals visiting farms. In order to do so, motivators and constraints for altered behaviour need to be identified.

- Not all pig farmers were aware that there was an outbreak of PRRS, even though written information had been sent to them, and media reported about the outbreak. Hobby farmers were identified as a group that was difficult to reach. Pig farmers seem to trust information from the veterinary authorities; however, it is important to find ways to reach all farmers with information during an outbreak.

7 Implications for future research

7.1 Validation of the livestock holding and movement databases

For any future research based on data from the SJV, validation of data is necessary to identify constraints and erroneous data. Such work is important for the databases to be reliable tools in case of an outbreak.

7.2 Frequency of farm visits

In addition to live animal movements, contacts through farm visits can spread disease. The frequency of farm visits are therefore of interest when assessing risk for disease introduction. Data reported by farmers (the farmers included in paper III) on the frequency of visits during four two-week periods (one each season) have been collected. These need to be analysed and can, combined with the results from biosecurity studies, provide useful input for disease control work and for disease spread models.

7.3 Patterns of farm visits and biosecurity among professionals visiting farms

Ambulatory staff often visit several farms each day and can potentially spread disease between farms. Therefore the movement patterns of such professionals are of interest to study, e.g. number of farms visited each day, and the geographical areas within which different groups of professionals work. Much of these data are available e.g. in registers for veterinarians, AI-technicians, dairy companies, feed companies; however, they have not been analysed from a disease control perspective. Although some data on use of protective clothing among professionals visiting farms were captured in this study, other routines such as equipment-cleaning can also be relevant and thus investigating bio-security among farm visitors is of interest. Furthermore, professional farm visitors could be asked about the frequency of some biosecurity routines used by the farmers and this could thus be assessed without influence on farmers' non-response.

7.4 Investigation of motivators and constraints for improved on-farm biosecurity using methods from social science

From the results it was concluded that improved on-farm biosecurity is needed. In order to achieve this, a necessary step is to investigate potential motivators and constraints, as well as persons or organisations which are important for influencing farmers' behaviour, using methods from social and behavioural science and to find ways to induce behavioural changes among farmers and professionals to improve biosecurity routines.

7.5 Investigating the successful biosecurity work

From the biosecurity study there were examples of high biosecurity routines, both among groups of farmers and professionals visiting farms. To investigate reasons for this, i.e. finding out which previous work aiming at improved biosecurity that has been successful, and why, could contribute to identifying effective methods for improving biosecurity in other groups of farmers and professionals visiting farms.

7.6 Risk based surveillance and disease control

The measure INGOING INFECTION CHAIN could be useful for disease surveillance and control, e.g. for control programmes for endemic diseases or in the design or evaluation of surveillance programmes or early detection systems of exotic diseases or for documenting freedom from disease. This could be explored by investigating associations between INGOING INFECTION CHAIN for relevant periods and prevalence data, e.g. for endemic viral diseases and salmonella.

7.7 Information to farmers in case of an outbreak

Based on our results, not all farmers were reached by information on how to protect their holding and how to identify clinical signs during an outbreak. For successful eradication and compliance it is important to reach all farmers with information. Research is needed to identify how different groups of farmers can be reached with information during outbreaks, and activities needed to ensure high compliance with recommendations or interventions.

7.8 Modelling of disease spread

The findings from these studies will in the future be used to parameterise disease models in a joint collaboration project with the aim to develop models to evaluate different scenarios for disease outbreaks and potential effects of intervention strategies.

8 Populärvetenskaplig sammanfattning

8.1 Bakgrund

Det finns flera olika anledningar att förebygga och bekämpa smittsamma sjukdomar hos produktionsdjur. Exempel på dessa är de ekonomiska aspekterna, eftersom flera sjukdomar antingen kan orsaka dödlighet eller minskad produktion i form av nedsatt tillväxt eller sänkt mjölkproduktion. Vissa av sjukdomarna som drabbar djur är också zoonoser, dvs. de kan både smitta djur och människor, antingen via direktkontakt, via miljön eller via livsmedel. Dessutom är skydd från sjukdom en viktig del av ett gott djurskydd.

Sverige har en lång tradition av sjukdomsbekämpning och har jämfört med många andra länder ett mycket gott läge vad gäller smittsamma djursjukdomar. Läget kan dock inte betraktas som något konstant. Flera allvarliga djursjukdomar, till exempel mul- och klövsjuka förekommer i stora delar av världen och globalisering med ökad handel och ökat resande ökar också risken för introduktion av sjukdomar som vi inte har i landet. För spridning av sjukdomar mellan gårdar spelar förflyttning av levande djur en stor roll. För att möjliggöra smittspårning vid ett allvarligt sjukdomsutbrott ska alla förflyttningar av nötkreatur och grisar enligt lag rapporteras till Jordbruksverket. Utöver spridning via direktkontakt mellan djur kan vissa sjukdomar spridas via djurprodukter eller indirekta kontakter, såsom fordon, eller besökare som varit i kontakt med djur, eller t.ex. gödsel. Risken för smittspridning via dessa kontakter kan minskas genom goda smittskyddsrutiner, t.ex. genom användande av rena skyddskläder i samband med gårdsbesök. Goda smittskyddsrutiner skyddar även mot flera av de smittsamma sjukdomar som vanligtvis förekommer i landet.

8.2 Sammanfattning av studier och resultat

För att undersöka mönstren av förflyttningar av levande nötkreatur och grisar mellan svenska gårdar undersöktes två omgångar av förflyttningsdata från Jordbruksverket, dels från juli 2005 till juni 2006, samt från januari 2006 till december 2008. De flesta förflyttningar skedde inom en radie på 10 mil från ursprungsgården. Det förekom dock längre förflyttningar, 5% av nötkreatursförflyttningarna och 9% av grisförflyttningarna var längre än 20 mil och förflyttningar upp till 120 mil för nötkreatur och 100 mil för grisar förekom. Förekomsten av långa förflyttningar stödjer införande av ett initialt så kallat "stand still", det vill säga ett totalt stopp för förflyttning av mottaliga djur om förekomst av mul- och klövsjuka skulle upptäckas i Sverige. De flesta besättningar hade inga eller ett fåtal direkta kontakter med andra besättningar genom djurförflyttningar. Dock fanns det ett antal besättningar som hade omfattande kontakter och på så sätt skulle kunna spela stor roll för smittspridning. Utöver de direkta kontakterna undersöktes kontakter i flera steg, där hänsyn togs till i vilken ordning förflyttningarna hade skett. Ett särskilt nätverksmått för detta togs fram, ett mått på hur många direkta och indirekta kontakter en besättning har genom djur som flyttas till gården. Av analyserna framgick att en del gårdar som har få direkta kontakter kan ha många indirekta kontakter. Det nya måttet skulle kunna vara användbart för sjukdomskontroll och sjukdomsövervakning och även för djurägare vid val av handelspartner. Jordbruksverkets databaser kan vara mycket användbara för sjukdomskontroll och bekämpning, och vissa förbättringar samt en kontinuerlig kvalitetssäkring av data skulle dock ytterligare kunna öka användbarheten.

Utöver djurförflyttningar undersöktes även smittskyddsrutiner på gårdsnivå genom en enkätstudie till 1498 djurägare med nötkreatur, grisar, får eller getter. Utav dessa inkom svar från 34 %. Bland de som avböjde att delta i studien var den vanligaste orsaken de inte längre hade djur på gården. Av studien framkom att smittskyddsrutinerna varierade mycket mellan olika gårdar. De som generellt hade bäst rutiner var gårdar med enbart grisar, jämfört med gårdar med nötkreatur, får, getter eller blandade djurslag. Dessutom var smittskyddet sämre på gårdar där djurantalet var litet. Av skriftliga kommentarer framgick att en del djurägare förväntade sig att bli informerade i tid innan ett utbrott för att hinna förbättra rutinerna, och hade således inte risken för smittspridning innan första fallet upptäckts i åtanke. Deltagarna i studien ombads även svara på frågor gällande användandet av skyddskläder bland besökare. Även där fanns en stor variation med bäst rutiner bland veterinärer och seminörer, men sämre bland t.ex. transportörer av levande djur som enligt vad som framkom av enkäten dessutom ofta var inne i stallarna. En slutsats från studien är att det finns behov av förbättring av smittskyddet på gårdsnivå och bland besökare. Med tanke på att många informationskampanjer för förbättrad smittskydd på gårdsnivå har genomförts är inte mer information hela lösningen. Undersökningar av vad som upplevs som hinder och vad som skulle vara motiverande för att förbättra smittskyddsrutinerna behöver genomföras.

Som en följd av utbrottet av grissjukdomen PRRS sommaren 2007 undersöktes djurägares sjukdomsmedvetenhet och informationssökning genom en enkätstudie till 153 djurägare med grisar. Under utbrottet skickade Jordbruksverket i samarbete med Svenska Djurhälsovården och Statens Veterinärmedicinska Anstalt skriftlig information om sjukdomen till samtliga djurägare med grisar, dessutom rapporterade media om utbrottet. Av studien framkom att djurägare med stora besättningar var väl medvetna om sjukdomen, men i gruppen djurägare med små besättningar hade inte alla nåtts av informationen och visste därmed inte om att det varit ett utbrott. En fjärdedel av djurägarna hade ändrat sina smittskyddsrutiner under utbrottet och sex månader senare hade två tredjedelar av dem fortfarande kvar de ändrade rutinerna. Gårdens avstånd till utbrottet påverkade i vilken grad djurägarna aktivt sökte information, och de djurägare som var nära utbrottet sökte i större utsträckning själva efter information. Svenska Djurhälsovården rapporterades som den viktigaste och pålitligaste informationskällan, följt av de veterinära myndigheterna (Jordbruksverket och Statens Veterinärmedicinska Anstalt, SVA).

Resultaten från dessa studier utgör ett vetenskapligt underlag för framtida sjukdomsövervakning och sjukdomskontroll. Vidare har områden identifierats där vidare forskning och utvecklingsarbete behövs.

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Acknowledgements

This work was carried out at the Department of Disease Control and Epidemiology at the National Veterinary Institute (SVA) and at the Division of Ruminant Medicine and Veterinary Epidemiology, Department of Clinical Sciences, Swedish University of Agricultural Sciences (SLU). Funding for the project was provided by the former Swedish Emergency Management Agency (KBM), currently Swedish Civil Contingencies Agency (MSB).

I would like to express my gratitude to everyone who contributed to the completion of this thesis, and especially:

Professor Ivar Vågsholm, thank you for being my main supervisor, for encouragement and interesting discussions where you often have contributed through seeing things from a different perspective. Tusen tack!

Associate professor Susanna Sternberg Lewerin, my supervisor, thank you for your excellent support from the very start of the project, for your devotion to disease control and for sharing your enormous knowledge in the area, for wholehearted encouragement at all times, and last but not least; for being a great boss.

Associate professor Ann Lindberg, my supervisor, thank you for sharing your great knowledge within the field of epidemiology, for always giving constructive feedback, for being quick as the wind and replying to my mails within nanoseconds, and for loads of enthusiastic encouragement.

Doctor Jenny Frössling, my supervisor, thank you for your warm and never ending encouragement, for being such a brilliant partner in developing ideas, for enjoyable collaboration, for your genuine support at times when life has been a bit tough, and for being the best guide to Stata I could ever ask for.

Anonymous reviewers, whoever you are, thank you for constructive feedback on my articles.

Scientific colleagues around the world, thank you for work that has been a source of inspiration for me. Some of you I have had opportunity to meet in real life, and others only through your publications. I would especially like to mention Marnie Brennan, Susan Robinson, Rob Christley, Cerian Webb and Caroline Dubé.

Göran Jönsson, at Veterinärmuseet in Skara, thank you for providing the picture for the introduction.

All farmers, thank you for your participation in the questionnaire studies, special thanks for letters, post-card and positive feedback on the project!

The SRTSE and the Neuroprion groups, thank you for not letting me totally forget the prions during the work with my thesis, especially Alexandre Fediaevsky, Sue Tongue, Petter Hopp, Giuseppe Ru, Dolores Gavier-Widén and Sylvie Benestad, I have really enjoyed working together with you.

My colleagues in Linköping and Skövde; Uno Wennergren, Annie Jonsson, Jenny Lennartsson, Tom Lindström and Nina Håkansson (Nina, I agree, it is exactly like Sudoku), thank you for all interesting and constructive discussions and good collaboration.

All members of the Epiforum, thank you for interesting and enlightening discussions.

All former and present PhD-students at the institution; Ane, Ann, Marie, Johanna, Nils, Emma, Jaruwan, Aran, Cecilia W, Cecilia L, Helena, Charlotte and Ann-Kristina thank you for Journal clubs and excellent travel and conference company. Special thanks to Lena for zillions of litres of tea at Marielundsgatan and for giving me last minute feedback.

Teachers and co-students at PhD-courses, thank you for guiding me to new areas of knowledge and for good company during the process of learning, I would especially like to thank Ingrid, Odd, Cicci, Oscar, Siamak, Lisa, Mads, Gunnstein, Andreas, Karl and Aragorn (can't believe he didn't stay for the whole course).

All PhD-students at SVA, especially Eva for great sports company, Erik (thanks for help with the templates), Sara and Oscar.

All colleagues at the Department of Disease Control and Epidemiology; Cecilia, Elina, Erika, Estelle, Eva, Helene, Kaisa, Lena, Linda, Marianne, Nilla, Patrik, Sofia, Stefan, Ulla C, Ulla M, I am privileged to have you as colleagues. Thank you for a great atmosphere, for laughter and for all discussions covering an immensely wide variety of topics. Special thanks to Marianne, doing a great job as the leader of the team.

Karin, Anton and Lena, thanks for helping me keep the endorphins at a decent level.

All friends at Uppsala Ju-jutsuklubb, and especially Per for the latest months of training, thanks for providing another focus besides my thesis.

Nachbar Greger and long-distance neighbour Maria, thank you for Tisdagsklubben.

Livia and Hanna, thank you for your encouragement and for keeping the emergency line open.

Fredrik and Linda, thank you for your support.

Agnes and Henri, thank you for being yourselves.

Mamma and Pappa, thank you for your support and for always being there for me, extra thanks for saving me from factory-made ready-cooked food this last month of constant writing.

ALL of my friends, no one mentioned and surely no one forgotten; thank you for sharing thoughts and ideas and moments of fun, frustration, challenges, laughter and tears. You are the best! Love you!