TITLE: Analysis of Swine Movements in a Province in Northern Vietnam and Application in the Design of Surveillance Strategies for Infectious Diseases

AUTHORS: E. Baudon, G. Fournié, D. T. Hiep, T. T. H. Pham, R. Duboz, M. Gély, M. Peiris, B. J. Cowling, V. D. Ton, M. Peyre

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Analysis of swine movements in a province in Northern Vietnam and application in the design of surveillance strategies for infectious diseases

Eugénie Baudon[1,2], Guillaume Fournié[3], Dao Thi Hiep[4], Thi Thanh Hoa Pham[2], Raphael Duboz[2], Marie Gély[2], Malik Peiris[1], Benjamin J. Cowling[1], Vu Dinh Ton[4], Marisa Peyre[2]

Author affiliations:

[1]School of Public Health, The University of Hong Kong, Hong Kong Special Administrative Region, China.

[2]Animal and Integrated Risk Management Research Unit (AGIRs), French Agricultural Research Center for International Development (CIRAD), Montpellier, France.

[3]Veterinary Epidemiology and Public Health Group, Production and Population Health Department, Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire, AL9 7TA, United Kingdom

[4]Hanoi University of Agriculture, Gia Lam, Hanoi, Vietnam

Address for correspondence:

Eugénie Baudon, HKU, 2/F Patrick Manson Building, 7 Sassoon Road, Pokfulam, Hong Kong.

Email: eugenie.baudon@gmail.com; Tel: +852 3917 6733/Fax: +852 3520 1945

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Summary

While swine production is rapidly growing in South-East Asia, the structure of the swine industry and the dynamic of pig movements have not been well-studied. However, this knowledge is a pre-requisite for understanding the dynamic of disease transmission in swine populations and designing cost-effective surveillance strategies for infectious diseases. In this study, we assessed the farming and trading practices in the Vietnamese swine familial farming sector, which accounts for most pigs in Vietnam, and for which disease surveillance is a major challenge. Farmers from two communes of a Red River Delta province (Northern Vietnam) were interviewed, along with traders involved in pig transactions. Major differences in the trade structure were observed between the two communes. One commune had mainly transversal trades, i.e. between farms of equivalent sizes, whereas the other had pyramidal trades, i.e. from larger to smaller farms. Companies and large familial farrow-to-finish farms were likely to act as major sources of disease spread through pig sales, demonstrating their importance for disease control. Familial fattening farms with high pig purchases were at greater risk of disease introduction and should be targeted for disease detection as part of a risk-based surveillance. In contrast, many other familial farms were isolated or weakly connected to the swine trade network limiting their relevance for surveillance activities. However, some of these farms used boar hiring for breeding, increasing the risk of disease spread. Most familial farms were slaughtering pigs at the farm or in small local slaughterhouses, making the surveillance at the slaughterhouse inefficient. In terms of spatial distribution of the trades, the results suggested that Northern provinces were highly connected and showed some connection with Central and Southern provinces. These results are useful to develop risk-based surveillance protocols for disease detection in the swine familial sector, and to make recommendations for disease control.

Keywords: network analysis, swine movements, infectious disease, disease surveillance, South-East Asia, Vietnam

Introduction

South-East Asia is considered as a hotspot for the emergence of zoonotic infectious diseases mostly due to anthropogenic factors (Coker et al., 2011, Jones et al., 2008). Swine is a host, mixing vessel or reservoir for many viral (e.g. Influenza, Japanese encephalitis, Nipah virus, Hepatitis E) and bacterial (e.g. Streptococcus suis) zoonoses which are major public health concerns in South-East Asia (Smith et al., 2011, Jones et al., 2013). The 2009 H1N1 influenza pandemic confirmed the importance of swine in the generation process of new influenza reassortants from avian, human, and swine influenza viruses. It also stressed the need for having an effective systematic surveillance of influenza viruses circulating in pigs at the global level (Vijaykrishna et al., 2011). The pig and poultry populations have at least doubled since 1990 in many South-East Asian countries, including Vietnam (Coker et al., 2011). Vietnam is the world's 13th most populous country with 88.8 million inhabitants (GSO, 2012), 4th largest pig producer with 26.2 million heads, and 10th largest poultry producer with 315.0 million heads (FAO, 2014). However, no sustainable surveillance program focusing on zoonotic diseases in swine such as swine influenza viruses (SIV) has been implemented so far; only short term research projects were carried out. Also, only a limited passive surveillance system is established for very contagious swine diseases such as Porcine Reproductive and Respiratory Syndrome (PRRS).

The knowledge of the structure and the dynamic of the pig value chain is a pre-requisite for understanding infectious disease transmission dynamics and for the development of cost effective surveillance systems. In Vietnam, the structure of the swine industry and its implication for disease surveillance has not been extensively studied. There are three main different types of farms: familial farms (hộ chăn nuôi), companies (Doanh Nghiệp) and state-owned farms (Trại Nhà nước). Familial farms are held by households, and often characterized as small (Nông hộ), medium (gia trại), or large farms (Trang trại); the actual size of each farm category may differ across the locations. Company farms are very large farms with a different legal status and

ownership. They are owned by foreign or Vietnamese companies, and usually under the management of several people; some companies own many farms. They also practice contract farming (Gia công) by providing financial and technical support to farmers. These farms are usually larger than the average familial farms. The company farms are mainly located around Hanoi and Ho Chi Minh City. Finally state-owned farms are large farms which often keep exotic breed great grandparents and grandparents. The familial small and medium holders (described as 1-100 fattening pigs or 5-20 sows) consisted of 84% of national pig herds in 2006, with a decline in the number of smallholdings and an increase in the number of medium-size holdings since 1999 (Fisher and Gordon, 2008). Indeed, the government promotes intensification of pig production, and as the smallholdings are often less robust to disease outbreaks, many small farmers stopped raising pigs, while other familial holdings converted to large scale pig production. In most familial farms and in some companies, the biosecurity level is low, promoting interspecies transmission of diseases such as influenza, and within- and between-herd transmission of swine diseases of economic importance, such as PRRS, Classical Swine Fever (CSF), and Foot and Mouth Disease (FMD) (Kamakawa et al., 2006).

Commercial movements of live animals are known to be a major pathway for disease transmission between domestic animal populations (Fevre et al., 2006). Therefore, a description of the pig value chain and the analysis of the network of commercial movements of pigs between farms would provide insights in the potential transmission dynamics of influenza and other swine diseases between farms. Analysis of this network would provide essential elements for the development of targeted surveillance strategies. Indeed, network analysis has been applied in preventive veterinary medicine since the early 2000s, and used to assess the influence of the distribution of contacts between animal populations from different stages of the value chain – such as farms, markets or slaughterhouses – on the disease transmission dynamics (Martinez-Lopez et al., 2009b). The position of these premises in the network are assessed, allowing the identification of the premises at higher risk of becoming infected, or of transmitting infection

(Dube et al., 2011). In Vietnam, there is no record of live pig movements and only a limited number of publications addressing this topic is available. Some studies described the pork value chain in Vietnam focusing on the distribution of meat (Lapar et al., 2003, ILRI, 2014), and the cross-border movements of live pigs and other livestock in South East Asia (Cocks et al., 2009). To our knowledge, no study of the live pig trade network in Asian countries has been done, while a few studies have been carried out in European countries and Canada since 2007 using commercial or governmental databases (Smith et al., 2013, Dorjee et al., 2013, Buttner et al., 2013, Rautureau et al., 2012, Noremark et al., 2011, Martinez-Lopez et al., 2009a, Bigras-Poulin et al., 2007, Thakur et al., 2014). In contrast, network analysis on poultry movements in Vietnam (Fournie et al., 2013, Soares Magalhaes et al., 2010), China (Soares Magalhaes et al., 2012, Martin et al., 2011), Cambodia (Van Kerkhove et al., 2009), and developing countries in other parts of the world such as Madagascar (Rasamoelina-Andriamanivo et al., 2014) were carried out. These studies conducted in Asia have pointed out the role of live bird markets in the dissemination of Highly Pathogenic Avian Influenza (HPAI) and provided useful insights for the surveillance and control of the disease in poultry.

The objective of the present study was to describe farming and trading practices in the familial swine sector in the Red River Delta region (RRD) in Northern Vietnam. Farmers in two communes in the RRD and traders involved in pig trades were interviewed. The geographical scale and the structure of the networks of contacts between farms resulting from pig trade were assessed. Hypotheses on the risk of disease transmission across the pig value chain were formulated for a comprehensive risk assessment that could be carried out in a separate future study. The identification of at-risk trading behaviors of premises was useful in the design of risk-based surveillance protocols for the detection of infectious diseases such as swine influenza.

Material and methods

Study area

The study was implemented in Northern Vietnam in the RRD, where the capital city Hanoi is located. The RRD alone includes about a quarter of the human, pig and poultry populations of the country in just 6.4% of its area (GSO, 2011b, GSO, 2011a, GSO, 2012). Hung Yen province was selected based on the following criteria: high density of pigs, economic importance of the pig production in the area, diversity of familial farming systems and trading practices. Following the same criteria as above, the study area was then narrowed down to two communes, *Dinh Du* (Com1) and *Me So* (Com2), within two adjacent districts, *Van Lam* (Dist1) and *Van Giang* (Dist2) located in the North of the province. These communes had similar characteristics such as the surface area (4.5 and 6.6 sq. km respectively), human population (7,100 and 9,600 inhabitants) (GSO, 2014), number of villages (four and six), and number of familial farms (158 and 141) (May 2012 data). These two communes were especially chosen as they differed in the ratio of the large familial farms over small-medium familial farms: Com2 had 3.5 times more large farms and 1.4 times less small-medium farms compared to Com1. Indeed, the dynamic of farming intensification was different in the two communes, and this may have an impact on trading networks.

Selection of farmers and data collection

Participatory interviews were carried out to collect preliminary data on the study areas, and inform the design of the questionnaires. Different pig categories were mentioned. Pigs for slaughtering, later mentioned as slaughter pigs, included fattening pigs which were from five to six months old, and incidentally cull pigs which were retired sows and boars. Weaners were about 2-month-old pigs that were fattened, and breeders included sows and boars for reproduction. The familial farms were categorized into small farms including Nông hộ (<100 fattening pigs per cycle and <10 sows) and large farms including Gia trại and Trang trại (≥100 fattening pigs per cycle or ≥10 sows). All the large farms were interviewed as their number was limited in each commune, whereas all the small farms from only one selected village in each commune were interviewed. Indeed, from the participatory interviews, it was estimated that the

156 farming and trading practices in each commune were homogeneous across the villages, and the
157 village with the highest number of small farms in each commune was selected.
158 Through questionnaire-based individual interviews, farmers were asked detailed
159 information on the structure of the farm, their breeding practices, and their purchases and sales of
160 pigs from January 2011 to June 2012. Indeed, at least one year of trading period was chosen
161 because of the duration of fattening pig production (around six months) and to account for the
162 potential seasonal increase in pig production due to the Tết holiday, the Vietnamese New Year,
163 occurring in January or February (during which consumption of meat increases). During the
164 interviews, free recall and free choice approaches were used to identify all the persons they had
165 traded with during the specified period of time; no a-priori list of stakeholders was provided.
166 Farmers with a larger number of trades were more likely to forget some of them, and also trades
167 of smaller sizes may have been omitted more frequently. This recall bias may have led to an
168 under-estimation of the number of trades and pigs, especially for large farmers with many trades.
169 The reports of trades between interviewed actors were checked for consistency later on.
170 **Selection of traders and data collection**
171 The interviewed farmers mentioned different pig buyers and sellers. Within a snow-ball
172 sampling approach, a sample of the actors involved in the trade of weaners and fattening pigs
173 (the most important trades in term of volume) was chosen for additional interview. This included
174 companies and traders such as traders owning or working in slaughterhouses, middlemen buying
175 and selling pigs directly between farmers, and middlemen buying pigs from farmers and selling
176 them in the live pig market in Com1. For each category, the most mentioned actors with
177 sufficient contact information were selected in priority across Hung Yen, Hanoi and the
178 surrounding provinces. Traders were asked general and detailed information on their activity,
179 including questions about the number of trades and pigs exchanged from January 2011 to June
180 2012. Contrary to farmers, traders could not provide a detailed list of their trades as there were
181 too many. Therefore, the total volume of trades and pigs traded over the study period were asked,

and then matrix scorings (Jost et al., 2010), a participatory method using proportions, was used to estimate the number of pigs traded and trades performed with each category of actor and location for both purchases and sales. All farmers and traders interviews were performed between June to September 2012.

Data processing

Data were entered in an access database and were cleaned and analyzed using R 3.1.1 (R, 2013). During farmers' interviews, potential inconsistencies between the answers provided to questions related to overall and specific trading activities were clarified. When important inconsistencies were noticed when cleaning the dataset, the paper form was checked, and if the error was not resolved, the interviewees were contacted again by phone for clarification.

Data analysis

Farm typology

A farm typology taking into account both the size and the type of production was carried out, as these characteristics were considered to influence farmers' trading practices. A principal component analysis followed by a hierarchical clustering was conducted. Five variables were included: number of sows and number of boars present at the time of the visit, average number of fattening pigs produced per year in the farm, and number of weaners purchased and sold from 2011 to June 2012. The farm classes resulting from the typology were then used in the rest of the analysis.

Descriptive statistics

First, we performed basic descriptive analyses of the farming and general trading practices. Then a detailed description of the trades from farmers and traders was performed for the different pig production categories, i.e. slaughter pigs (fattenings and cull pigs), weaners and breeders. Fattening and cull pigs were not moved from farms to farms, but to slaughterhouses; these movements can be considered as dead ends for disease circulation. Greater focus was brought on the movements of pigs between farms, directly or through middlemen, which involved weaners

208 and breeders. Cytoscape 3.2.0 was used to draw diagrams showing the movements of pigs
209 between the different categories of actors (Smoot et al., 2011). Trades were qualified as
210 transversal when performed between farms of equivalent sizes, and as pyramidal when
211 performed between farms of different size, e.g. from larger to smaller farms. For the graphs
212 representing weaners and breeders trading from farmers in both communes, a bimodal approach
213 was used, i.e. sales and purchases were treated and represented separately. Loops were
214 eliminated by this process, and trades between interviewees were counted twice, once as sales
215 and once as purchases in order to clarify the direction of trades, i.e. transversal or pyramidal.
216 *Analysis of egocentric networks*
217 Commonly within an animal movement network, nodes represent individual premises part of the
218 value chain, and the links between two nodes represent animal movements. The links are called
219 *arcs* in a directed network where one of the node is the sender or seller and the other is the
220 receiver or buyer (Dube et al., 2011). Egocentric networks were built for each of the 137 farms
221 based on weaner and breeder trades using the R package igraph (Csardi and Nepusz, 2006). This
222 analysis was chosen over the construction of one network in each commune involving all
223 interviewed and mentioned actors because about 90% of the trades were done with non-
224 interviewed actors and the networks would have been incomplete.
225 Each egocentric network was composed by nodes representing an interviewed farmer and
226 his trading partners, mentioned as large or small farmers, companies, middlemen, or market. The
227 market was considered as one node with a unique location, although many middlemen would
228 also be present in the market. Ideally a node should be defined by a premise where pigs would
229 stay at least a few hours like in slaughterhouses and markets, but some middlemen carried pigs
230 directly from farms to farms. However the farms of origin or destination were not known for
231 middlemen trades, and therefore it was not possible to replace these middlemen by arcs to farm
232 nodes. The arcs represented the movements of weaners and/or breeders from nodes selling to
233 nodes buying the pigs. For each interviewed farmer, two egocentric networks were built with

arcs characterized by two different weights, being the number of trades and the number of pigs traded from January 2011 to June 2012. Thus 274 egocentric networks were built.

For each interviewed farmer, different values of degrees were calculated. The in- and out-degrees were the number of actors selling pigs to and purchasing pigs from this farmer, respectively. Similarly, the pig weighted in- and out-degrees were the total number of pigs a farmer purchased and sold respectively. And finally, the trade weighted in- and out-degrees were the total number of trades a farmer performed for purchase and sale. Clustering coefficients could not be calculated as most of the trades were done with non-interviewed actors and therefore in the majority of the egocentric networks, the links between the actors mentioned by the farmer were missing. Based on these six values of degrees, a network typology was carried out using the same methodology as for the farm typology. The correlation coefficients between the different variables were calculated, and when they were above 0.8, one of the two variables involved was excluded. As a result, the networks were grouped into different classes according to their degree values. Finally a descriptive analysis of the networks and of these different classes was done in relation with the farm classes and other practices related to pig movements such as boar hiring.

Description of the geographical distribution of the trades

First, the spatial distribution of the trades generated by farmers was compared at the province level between Com1 and Com2. Then, middleman trades were analyzed to see if they were likely to link different provinces through pig movements. Finally, the general movements of live pigs were described geographically for all pig categories based on farmers and traders interviews. A map of all these trades across Vietnam was drawn using ArcGIS® 10.1; for this purpose the trades mentioned by the farmers with the interviewed traders were deleted as it was considered that these trades were included in the traders' transactions. For the trades done with middlemen and markets, the trader origins were taken into account as the locations of the farms of origin or destination were unknown.

Results

Study sample

A total of 158 farmers were listed by the village veterinarians including all the large farms in both communes and the small farms in both selected villages. However, some pig farmers were not listed, some farmers had stopped their activity by the time the study started, and some were not available or refused the interview. Finally, 137 farmers were interviewed, including nine large and 40 small farmers in Com1, and 41 large and 47 small farms in Com2.

About 100 companies and traders in 11 provinces were identifiable by their name, and were mentioned in 350 trading occasions. In 58 occasions, the information given by the interviewed farmer was not sufficient to identify the trading partner, 95% of these being slaughterhouses. Finally, a total of 11 slaughterhouses, 22 middlemen, and two companies were interviewed in five provinces, accounting for over 30% of all buyers and sellers mentioned and half of the trading occasions. The 22 interviewed middlemen included 17 middlemen exclusively trading weaners, with nine of them operating in weaner markets, three middlemen exclusively trading fattening pigs, and two middlemen trading both weaners and fattenings. Only 10% of the companies mentioned were interviewed accounting for about 20% of the trading occasions with companies.

General production and trading practices

Four classes of farms were obtained from the farm typology (Additional file 1 Figure 1). Three classes represented a total of 41 large farms of different production types (farrow-to-finish and fattening), while the fourth class grouped 96 small farms without discriminating the production type. The class containing the 96 small farms was then divided into two production types equivalent to the production types obtained for the large farms. Thus, the 137 farmers were divided into five classes. A summary of the typology variables for each of the farm classes is presented in Table 1. A total of 62.8% of the farms were specialized in a finishing activity, i.e. fattening 2-month-old weaners until slaughtering, and were divided in two classes defined as

large fattening farms (LF) and small fattening farms (SF). The three other classes were farrow-to-finish farms of different sizes with very large farms (VB), large farms (LB), and small farms (SB). Contrary to fattening farms, they didn't need to purchase weaners due to their breeding practice. Among the LB farms, three had a farrowing activity only. Although they were all familial farms, the VB farms had a very high number of pigs similar to some companies. Most of the large farms (VB, LB, LF) were found in Com2, while in Com1 and Com2 a similar number of small farms were interviewed in each village (SB, SF). These results show that the familial farms of different sizes have a specialized pig production which may influence their trading behaviors.

A descriptive analysis of trading practices was performed for the different pig categories in each commune (Table 2). Farmers in Com2 were trading more pigs (over 50,000 pigs traded) compared to Com1 (about 8,000 pigs traded). This was especially true for weaners which were mainly purchased by local farmers in Com1, whereas in Com2 weaners were both purchased and sold in high quantities by the interviewees. Pig farming was the most important source of income for the majority of the interviewees, so they usually remembered the trades they had done within the last 1.5 year. However, for the trades done between interviewees, involving breeders and weaners, three quarters (37/49) of the links were only reported by one out of the two interviewees involved in the exchange. The exchanges of larger numbers of pigs were usually better remembered as compared to smaller volume of trades. No other differences were found between the trades that were forgotten or remembered.

Trading practices for slaughter pigs

The analysis of the sales of slaughter pigs among the farmers showed important differences between the two communes (Figure 1). In Com1, farmers sold about three quarters of the pigs to traders slaughtering at the farm, while in Com2 a similar proportion of the pigs were sent to slaughterhouses. The farmers mentioned several categories of traders involved in fattening pig transactions. Two traders in collective slaughterhouses in Hanoi, nine local slaughterhouses and

five middlemen in Hung Yen and adjacent provinces were interviewed, and their trading practices were described (Additional file 1 Table 1). In the collective slaughterhouses, several independent traders were slaughtering pigs from many farms every night, mainly companies and large farms. In local slaughterhouses, pigs from only one or two farms were slaughtered per night, mostly from familial farms. Some seasonal variations were observed with an increase of the number of pigs slaughtered for a few days during the Tết holiday. However this seasonal effect for pig trade was not acknowledged by farmers or middlemen and was probably limited. These practices will have a direct impact in term of disease surveillance. Collective slaughterhouses seem the most suitable for sampling pigs from a high number of farms. On the opposite side, pigs slaughtered at the farm will not be easily accessible for sampling.

Trading practices for weaners and breeders

The distribution of the trades for weaners and breeders according to the trading partner activities were represented in Figure 2 for each pig category in each commune. In the two communes, mostly fattening farms were responsible for the purchases of weaners. These pigs were mainly purchased indirectly through middlemen and the market (61.7%) by the small fattening farms in Com1, and directly from other farmers (86.6%) by the large and small fattening farms in Com2. Farrow-to-finish farms in Com1 were selling only a few hundreds of weaners, while the one in Com2 were responsible for the sale of above 16,000 weaners. Overall, the large farms in Com1 were almost completely inactive in term of weaner trades, while the three VB farms in Com2 accounted for 61.4% of weaners sales in that commune.

The trades were qualified as pyramidal when the pigs were going from farms of larger sizes (companies, large farms) to farms of smaller sizes (large farms, small farms), and transversal when the pigs were exchanged between farms of same size. In Com1 the interviewed middlemen (n=10) mentioned trading with many actors (Figure 3a), while the traders interviewed in the market (n=9) reported purchasing weaners mainly from small farmers (Figure 3b). Therefore, in Com1, the trades appeared to be mainly transversal between small farms,

directly or through the market. In Com2, an important part of the trades were clearly pyramidal for both purchases (60.6%) and sales (50.1%). The companies interviewed reported selling 64.6% of their weaner production to familial farmers, confirming the strong pyramidal structure.

Regarding the breeder trades, only a few hundreds were purchased and only a few dozens were sold altogether. In both communes, most of these trades were done directly between farms. The breeders were mainly purchased from companies, including breeding companies, and in general the purchases were almost exclusively pyramidal trades. The sales were done only locally in the same commune between familial farms.

Analysis of egocentric networks

Ninety-eight egocentric networks in Com1 and 176 in Com2 were built from the interviewed farmers; they were describing the trades of weaners and breeders between actors. An additional 67 actors in Com1 and 139 actors in Com2 were mentioned by the farmers and composed the networks, accounting for a total of 97 and 261 arcs respectively. The network sizes, i.e. the number of nodes, varied from one to 13 in Com1 and one to 22 in Com2 with a median of 3.0 and 3.5 respectively. VB and LB farms in Com2 had larger networks compared to other farms in Com1 and Com2, confirming the higher trading dynamism of these farm classes in Com2.

For the network typology, five variables were kept after exclusion of the trade weighted out-degree variable because of its high correlation coefficient with the pig weighted out-degree (0.97) and the out-degree variables (0.82). Four classes were identified (Additional file 1 Figure 2), and a summary of all the variables is available in Table 3. The first group was designated as isolated farms as they had null to low in-degree measures with null to medium out-degrees, i.e. they had limited trading interactions with other farms. The farms named as primary and secondary sinks had null to low out-degrees and respectively high and medium in-degrees, therefore they were receiving pigs but not redistributing. Finally, farms with high out-degrees were classified as sources, as they were at the origin of many sales; they also had medium in-degrees making them act as mediators for the movements of pigs, comparatively to the other

farm classes. The companies were not included in the typology as a focus was done on familial farms. However, they could also be considered as sources for the familial farms. The sources were VB and LB farms in Com2, while these same farm classes in Com1 were either sinks or isolated farms (Table 4). LF farms and about half of SF farms were primary sinks due to their important finishing activity. The remaining SF farms were mostly secondary sinks, i.e. with less important purchases. Most SB farms were isolated as they had limited trades, probably due to their small size and self-sufficiency in term of weaner supply with reproduction on the farm.

Boar hiring and its impact on the swine movement networks

Boar hiring was also mentioned as pig movements other than trades. About half of the farms with sows (42 farmers) reported hiring boar from other familial farmers. This practice was the most common in small farms, and in Com1 where about 90% of farms with sows hired boars compared to about 50% in Com2 (Additional file 1 Table 2). The network classes affected were the isolated farms and primary and secondary sinks. The degree variables for the farms hiring boars, originally based only on sales and purchases, were recalculated including and excluding the boar movements, to assess the impact of this practice on the classification of the farms (Additional file 1 Table 3). In general, the number of pigs did not increase dramatically as only one boar was exchanged at a time, while the frequency of exchanges or trades increased consequently, connecting many originally isolated farms with others.

Spatial analysis of swine movements

Differences were observed in the spatial distribution of the farmer trades between sales and purchases, between communes, and between pig categories (Additional file 1 Figure 3). In general, farmers in Com2 were trading with actors from multiple different provinces (4 to 7 provinces) compared to Com1 (2 to 4 provinces). The largest proportion of pigs was traded with Hung Yen for slaughter pigs (87.0% and 56.5% for sales) and weaners (93.2% and 94.6% for sales, 75.2% and 36.2% for purchases) for Com1 and Com2. Most of the slaughter pigs trades involved a limited number of provinces all located around Hung Yen. Weaners were traded

between more provinces in the RRD and North Vietnam. Breeder trades involved the highest number of provinces, including provinces from Southern Vietnam, probably due to the high genetic quality of the breed offered in that region. Breeders were purchased in majority from Hanoi (51.2% in Com1 and 67.0% in Com2).

Thirteen provinces in the RRD and the North were mentioned by the traders for weaner trades and 13 provinces in the RRD, the North and the South for fattening trades (Additional file 1 Figure 4&5). However, most of the traders were trading pigs within the RRD, and especially Hung Yen and the three adjacent provinces. Among weaners and fattening middlemen, three mentioned buying and selling in only one province (Hung Yen), while for 19 middlemen, the provinces used for purchases were not all the same than those mentioned for sales. This demonstrated that they were involved in pig movements between different provinces.

Overall, the trades generated by all interviewed traders and farmers for all pig categories involved the movement of a total of about 900,000 pigs across 22 provinces including Hung Yen over the 1.5 year study period (Figure 4). They were distributed all over Vietnam, with a focus on the North, and especially the RRD. Trades including the South were related to breeder purchases.

Discussion

This study provided a detailed descriptive analysis of the farming systems and live pig movements in two communes of the RRD in Northern Vietnam. The farm typology and the analysis of the farm networks provided important information for the identification of trading behaviors at risk for contagious disease spread, and for the development of targeted surveillance strategies. Cost-effective surveillance protocols are needed which allow the monitoring of diseases at a reasonable and therefore sustainable cost. Risk-based surveillance is the best approach and may have different goals (Cameron, 2012). Disease detection is a common goal for example for virus characterization, in the case of SIV in order to study the zoonotic potential of

the viruses or for PRRS to develop vaccines matching the circulating strains. Another goal is to demonstrate freedom from disease; this is more often used in developed countries for trading purposes, while in Vietnam most of the major swine diseases are endemic. Finally, early detection of a disease is often sought in order to contain its spread by implementing different control measures (e.g. trade restrictions), for example in the case of a PRRS outbreak. Disease mitigation can also be done by implementing preventive measures such as the increase of the general biosecurity level**.** Due to limited resources, farming systems at high risk of disease spread to an important number of other farms need to be targeted in priority. The design of risk-based surveillance protocols and control measures require the identification of farm categories with a higher risk of disease introduction and maintenance on one hand and disease spread on the other hand, and the identification of suitable focal points for targeted sampling is also valuable.

Although the study sample was limited as it was designed to be exhaustive at the local level, our data analysis showed an important diversity of practices among familial farms. Moreover, as the study province is one of the most dynamic in terms of pig production in the RRD, it could be considered that most of the different trading behaviors found in this region were also found and documented in the study area. The study provided insights in the dynamic of local pig production and trades. However, as the study focused on familial farms, the company sector was not thoroughly investigated and additional studies should focus on this sector to fully apprehend its role in terms of pig movements and risk in disease spread between sectors. It was pointed out that trades were sometimes forgotten by farmers, especially when small, therefore the swine commercial exchanges may have been under-estimated. In addition, because of the lack of detailed contact information in some instances, it was not possible to interview all of the trading partners mentioned by the interviewees and to perform an analysis of the complete trading network. Therefore in future studies, we recommend that movement network analysis be carried out by asking farmers and traders to keep written records of all sales and purchases. In the current study, only traders near Hung Yen and Hanoi were interviewed, as most of the traders

442 mentioned were located in that area. The geographical extent of the trades may therefore have
443 been underestimated, however many provinces were mentioned suggesting that provinces in
444 Northern Vietnam are highly connected through the pig trade. Since traders were not able to
445 provide the exact number of pigs traded by actor category and location, only general trends were
446 investigated using matrix scoring. This method does not provide precise numbers but it provides
447 reasonable estimates particularly of the relative proportions for the volume of pigs by actor and
448 location. This analysis allowed a reasonable description of the farming systems, of their trading
449 practices, and allowed farm classification according to the direction and volume of pig
450 movements which could be interpreted in term of risk of disease introduction and spread. The
451 risk of disease introduction and spread in low biosecurity settings such as Vietnam familial
452 farming is likely to be linked to trading behaviors and the corresponding animal and human
453 movements.

454 Indeed our typology of the familial farms performed within this study allowed going
455 beyond the simple distinction between small and large farms. Our results showed that farms had
456 a very specialized pig production, as in industrialized countries, with farrow-to-finish and
457 fattening farms of different sizes (Table 1). However, very few farms had an exclusive farrow-to-
458 grower activity, and no farms had a nursery activity (pigs from three to 10 weeks of age) as it is
459 described in western countries (Noremark et al., 2011, Dorjee et al., 2013, Rautureau et al.,
460 2012). On the overall farmers in Com1 had less dynamic trading practices as compared to those
461 in Com2 (Table 2), where a higher level of intensification of the familial pig production was
462 observed (with a higher number of large and very large farms). The trading practices were very
463 different between the two communes and the different types of production. The structure of the
464 trades differed between Com1 with mostly transversal trades (between farms of same size), and
465 Com2 with mainly pyramidal trades (between farms of different size) (Figure 2). Moreover, the
466 pyramidal structure of the pig production had a double sense here, with pig movements going
467 from larger to smaller farms, but also from farms with a farrowing activity to fattening farms.

468 This type of trade structure is found in industrialized countries as well as described in the
469 network analysis studies cited previously. Due to these trade structures, transmission of diseases
470 through live pig movements is more likely to occur between farms of similar size through
471 transversal trades and from larger farms toward smaller farms through pyramidal trades. In the
472 absence of appropriate biosecurity measures, the companies could play an important role as
473 sources of disease spread to the familial sector through the sales of breeders and weaners.
474 Specific types of production also had specific trading practices and thus different risk of disease
475 spread. In terms of disease transmission risk through trade, sources are generally considered at
476 high risk of disease spread to other farms, and sinks have a high risk of receiving the disease.
477 Here, the farms defined as sinks were fattening farms with important purchases of weaners; they
478 are potentially at higher risk of disease introduction due to pig movements, but probably have a
479 lower chance of spreading the disease through trade due to their limited number of sales to other
480 farmers, as pigs are mainly sent to slaughterhouse (Tables 3&4). The source farms, which were
481 large farrow-to-finish farms with moderate purchases (replacement of breeders) and important
482 sales to other farmers (mainly weaners and some breeders), would have a non-negligible risk of
483 disease introduction, and a high risk of spreading the disease to other herds. On the opposite, the
484 small farrow-to-finish farms in both commune and the large ones in Com1 were considered as
485 isolated farms and would therefore play a limited role in disease transmission risk through pig
486 trading networks. No farms showed both high in- and out-degrees, and therefore they are not at
487 high risk of disease introduction and spread (act as a hub), as it was described for nursery farms
488 in a study in Canada (Dorjee et al., 2013).
489 Therefore, one could consider that farms in Com1 would be less at risk for disease
490 spread, having a more limited number of trades. However, other at-risk practices, also shared
491 with some farms in Com2, were identified through the study. Firstly, middlemen and market
492 were more frequently involved in Com 1 swine purchase activities which increase their risk of
493 disease introduction (Figures 1&2). Indeed, middlemen often kept traded pigs in their house

where they also sometimes raise pigs. In the market pigs would stay for a few hours next to other pigs with different origins, sometimes being transported back and forth to the trader's house and potentially to other markets if unsold. The risk of transmission by fomites and people during these trades could also be important. Farmers in Com2 preferred buying pigs directly from other farmers so they could check the health status of the herd. Secondly, in Com1, more farmers were hiring boars for reproduction, being more popular among small farmers in general (Additional file 1 Figures 4&5). This practice may increase the role in disease transmission of farms considered as isolated regarding the other types of trades, through boar infection or fomite contamination.

The spatial distribution of the trades observed in this study highlighted the geographic extent of the pig movements, although most of pigs were usually traded within the RRD region (Figure 4). Overall, over 20 provinces in all Vietnam, i.e. about a third of the provinces in the country, were mentioned for trades described in this study which involved 173 actors interviewed in a limited geographical area. Based on these data, swine diseases are likely to spread easily and quickly within the RRD and Northern Vietnam as controls and health certificates requirements are not well regulated and because of the occurrence of asymptomatic diseases such as swine influenza.

According to the study results, fattening farms with high numbers of pigs purchased (i.e. sink farms) should be targeted in the design of a risk-based surveillance for disease detection and virus isolation for genetic characterization. Indeed targeting these farms would increase the sensitivity of surveillance compared with a randomized sample including all farms. This is probably true for fattening companies with low biosecurity as well. The large farrow-to-finish farms buying breeders and selling weaners seemed the most at risk for disease spread. They should be targeted along with companies for implementing disease prevention and control measures because of their high potential to spread diseases to other farms. This could be done by improving the general biosecurity level of these farms, and also by the early detection of diseases

in these swine herds before it spreads down to the chain. Since these farms are large and with constant renewal of the susceptible pig population, disease persistence might be high; they could also be considered in a risk-based surveillance design for disease detection, together with the fattening farms. Studying the disease transmission dynamics within these farms may be of interest to support the decision to include them in risk-based surveillance protocols. Similarly, larger fattening farms may show a higher persistence of viruses and may be more of interest compared to smaller farms. Developing risk-based surveillance protocols in areas like Com1 may be more difficult as no farms with high risk were identified, and few large farms were present. Although other risky behaviors were more frequent in this commune like boar hiring, the chances of isolating viruses might be low as the window of infection in such small pig herd would be short, and therefore the surveillance program might not be cost effective.

Finally, this study also allowed the identification and description of focal points that concentrate pigs from many farms. Sampling in these places would require fewer resources and would be more effective than sampling in individual farms. Local slaughterhouses were not considered as an efficient location for risk-based surveillance as they usually hosted pigs from only a few farms in a given day (Additional file 1 Table 1). On the contrary, collective slaughterhouses represented a very promising candidate for risk-based surveillance design for disease detection because pigs slaughtered in a same night had come from many farms and many provinces. Pigs were usually transported from Northern provinces within the same day, and held at the slaughterhouse for a few hours up to 36 hours before slaughter. Pigs from several farms were often mixed in the same pens and this may facilitate cross infection of non-immune animals and amplification of virus within this setting. Pigs in collective slaughterhouses came mostly from companies and secondarily from large familial farms. The other type of focal point identified was the weaner market. As the pigs present originated mostly from small familial farms in the RRD, this location was considered as interesting to cover this farming sector. However, this type of markets was not frequent in the region and only three were identified with

a geographic coverage much smaller compared to collective slaughterhouses. It was reported that sick pigs were often sold for slaughter, but in the case of the market, it would be likely that middlemen would sell only healthy-looking pigs to farmers, although some diseases like influenza may be asymptomatic. The age of the pigs sampled would also have an impact, with weaners being young pigs which might still be partially protected by maternal antibodies and fattening pigs being older pigs that may have been infected earlier in life and not be shedding virus at the time of slaughter. In the example of swine influenza viruses, to date virus isolation in Vietnam has only been reported in the company or industrial sector (Ngo et al., 2012), although there is serological evidence for influenza circulation in the familial sector (Trevennec et al., 2012). This study highlighted the challenges brought by the structure of the pig value chain which would explain this low detection rate of swine influenza in the familial sector and provide new information on how to overcome such challenges for cost-effective surveillance design of infectious diseases in swine.

Conclusion

This study has provided empirical data on the organization of the pig value chain in Hung Yen province in the RRD. Indeed, the analysis of animal movements represents a challenge in developing countries where systematic record keeping is not well established. This study allowed us to formulate hypotheses on disease transmission between farming systems and geographic locations, providing critical information for the design of risk-based surveillance protocols. Pilot trials of these protocols are currently ongoing to identify the most cost-effective protocols for swine influenza surveillance in Vietnam.

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690 **Table 1 Median (Min-Max) of the different variables for the different classes of swine**
691 **farms identified**

Class	Sows	Boars	Weaners sold	Weaners purchased	Fattenings per year	No of farms (Com1;Com2)
VB	**185 (70-250)**	**5 (3-6)**	1460 (0-6980)	0 (0-0)	1520 (600-2100)	**4** (1 ; 3)
LB	**26 (10-70)**	1 (0-5)	112 (0-1320)	0 (0-0)	248 (0-700)	**22** (5 ; 17)
SB	**4 (1-12)**	0 (0-0)	8 (0-61)	0 (0-34)	64 (20-160)	**25** (12 ; 13)
LF	0 (0-4)	0 (0-0)	0 (0-0)	**500 (280-970)**	300 (140-900)	**15** (0 ; 15)
SF	0 (0-13)	0 (0-0)	0 (0-0)	**80 (10-253)**	60 (15-300)	**71** (31 ; 40)

692 VB= Very large farrow to finish farms, LB = Large farrow to finish farms, SB = Small farrow to finish farms, LF =
693 Large fattening farms, SF = Small fattening farms.
694
695

696 **Table 2 General trade description per pig category in both communes over a 1.5 year**
697 **period**

Type of trades in the two communes	Slaughter pigs		Weaners		Breeders	
	Pigs	Trades (p/t)	Pigs	Trades (p/t)	Pigs	Trades (p/t)
Total No in Com1	**6086**	**363** (12)	**1886**	**153** (12)	**86**	**16** (5)
Purchases (%)	0	0	81.4	82.3	96.5	87.5
Sales (%)	100	100	13.1	11.8	0	0
Trades between interviewees (%)	0	0	5.5	5.9	3.5	12.5
Total No in Com2	**24243**	**1050** (26)	**26724**	**576** (40)	**597**	**62** (8)
Purchases (%)	0	0	39.6	33.2	93.5	87.1
Sales (%)	98.6	98.4	53.0	55.0	0	0
Trades between interviewees (%)	1.4	1.6	7.4	11.8	6.5	12.9
Com2/Com1	**4.0**	**2.9** (2.2)	**14.2**	**3.8** (3.3)	**6.9**	**3.9** (1.6)
Com2/Com1 adj. (*)	**2.2**	**1.6**	**7.9**	**2.1**	**3.9**	**2.2**

698 (p/t) Average number of pigs per trade; (*) Ratios adjusted by the number of farms in each commune.
699

700

701 **Table 3 Median (Min-Max) of the different variables for the network classes identified**

Class	Out-degree	Trade weighted out-degree	Pig weighted out-degree	In-degree	Trade weighted in-degree	Pig weighted in-degree	Total no of farms
Isolated farms	0 (0-4)	0 (0-5)	0 (0-239)	1 (0-1)	1 (0-2)	1 (0-40)	34
Primary sinks	0 (0-1)	0 (0-1)	0 (0-1)	3 (1-12)	5 (3-16)	176 (30-970)	48
Secondary sinks	0 (0-2)	0 (0-4)	0 (0-85)	2 (1-2)	3 (1-7)	50 (2-220)	42
Sources	6 (4-19)	18 (5-126)	690 (100-6980)	2 (1-3)	2 (1-5)	20 (3-117)	13

702 Degree measures were based on trades of weaners and breeders only.

703

Table 4 Proportions of farm classes pertaining to the network classes

Class	VB	LB	SB	LF	SF
Isolated farms	-	31.8 (3 ; 4)	84.0 (12 ; 9)	-	8.4 (4 ; 2)
Primary sinks	-	-	-	100 (0 ; 15)	46.5 (12 ; 21)
Secondary sinks	50.0 (1 ; 1)	18.2 (2 ; 2)	16.0 (0 ; 4)	-	45.1 (15 ; 17)
Sources	50.0 (0 ; 2)	50.0 (0 ; 11)	-	-	-
Total no of farms	**4**	**22**	**25**	**15**	**71**

Percentage and number of farms in commune 1 and in commune 2: "Percentage (No in Com1 ; No in Com2)"

Figure 1 Trade distribution for slaughter pigs across actor categories in each commune

Percentages of pigs traded (n_{Com1}=6086, n_{Com2}=24243); NA = buyer activity unknown, Slaughter mixed = traders with different slaughtering activities.

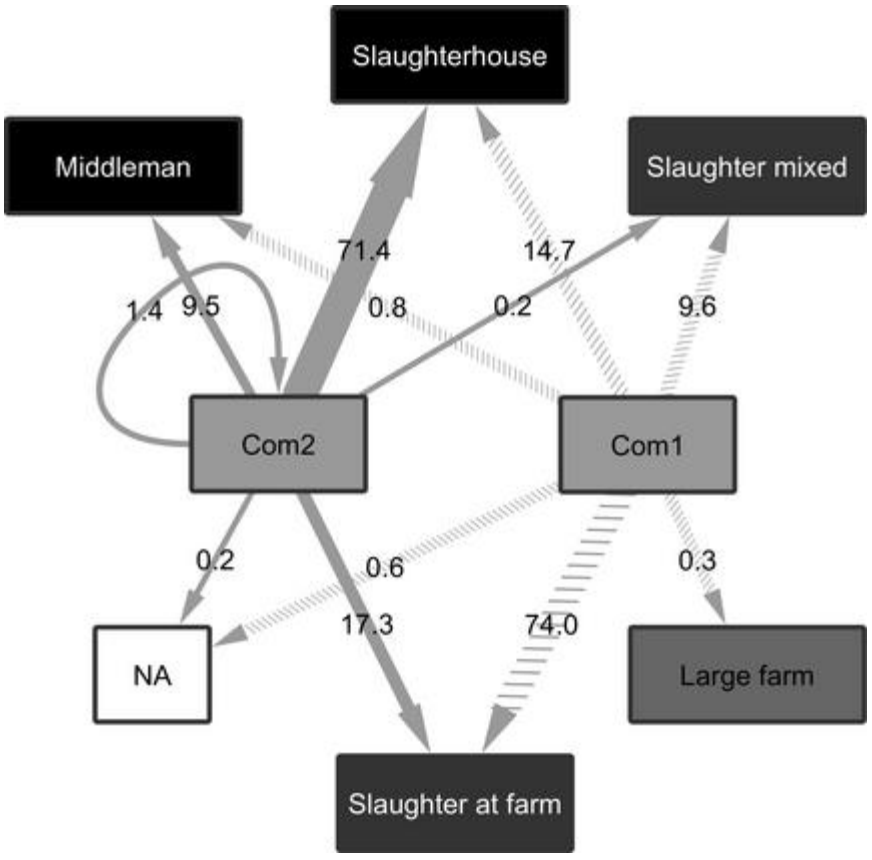

Figure 2 Trade distribution for weaners and breeders between actor categories in each commune

Percentages of purchased weaners (n_{Com1}=1640, n_{Com2}=12563) and breeders (n_{Com1}=86 pigs, n_{Com2}=597) from the different actor categories and sold weaners (n_{Com1}=351, n_{Com2}=16131) and breeders (n_{Com1}=3, n_{Com2}=39) to the different actor categories; trades between interviewees are counted twice as sales and purchases separately. Arrow widths are proportional to the number of pigs traded.

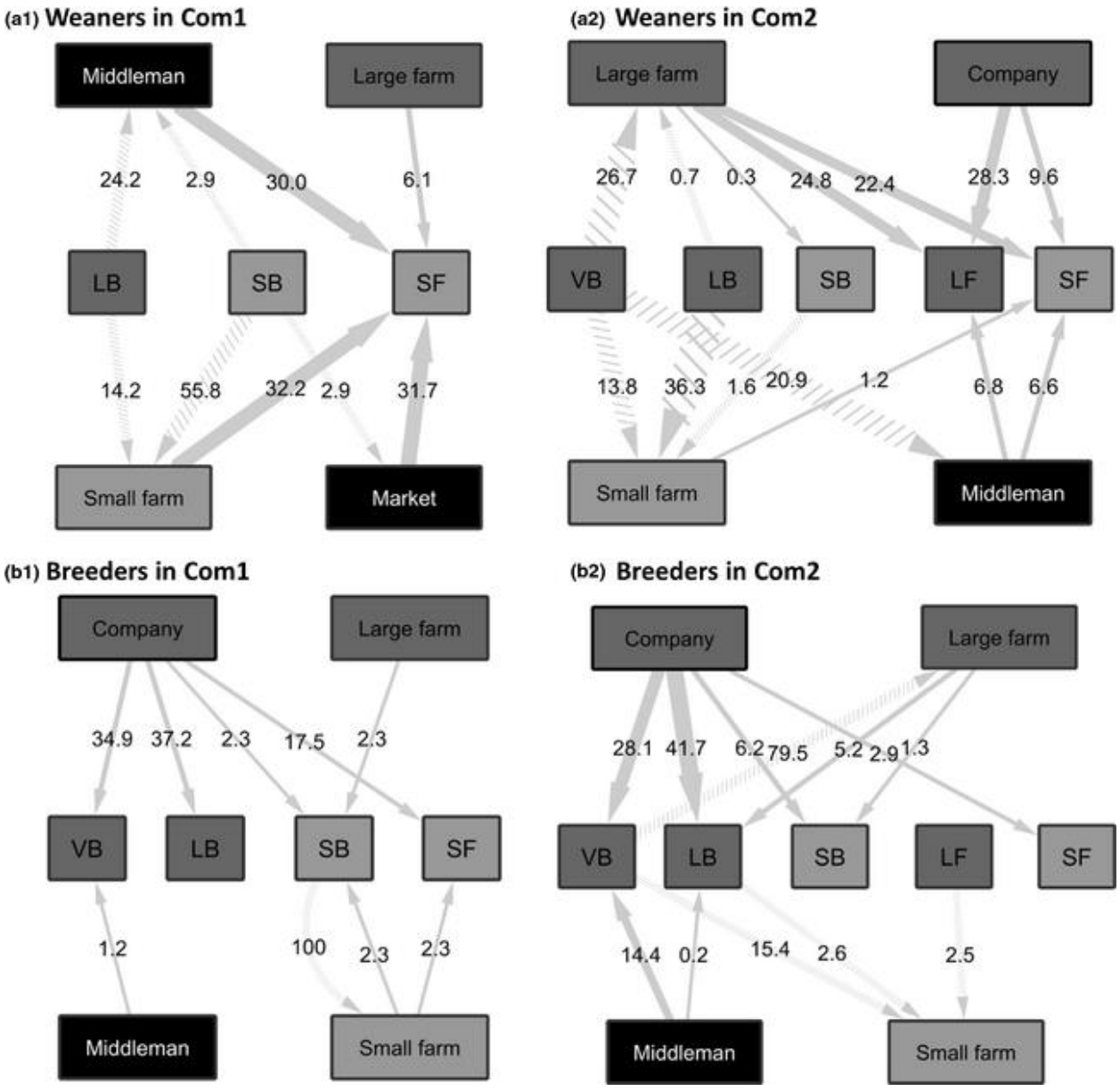

Figure 3 Distribution of weaner trades generated by interviewed middlemen (a) and market traders (b)

Percentages of weaners purchased and resold by independent middlemen ($n_{middlemen}$=202864 pigs) and middlemen from the market in Com1 (n_{market}=40870 pigs).

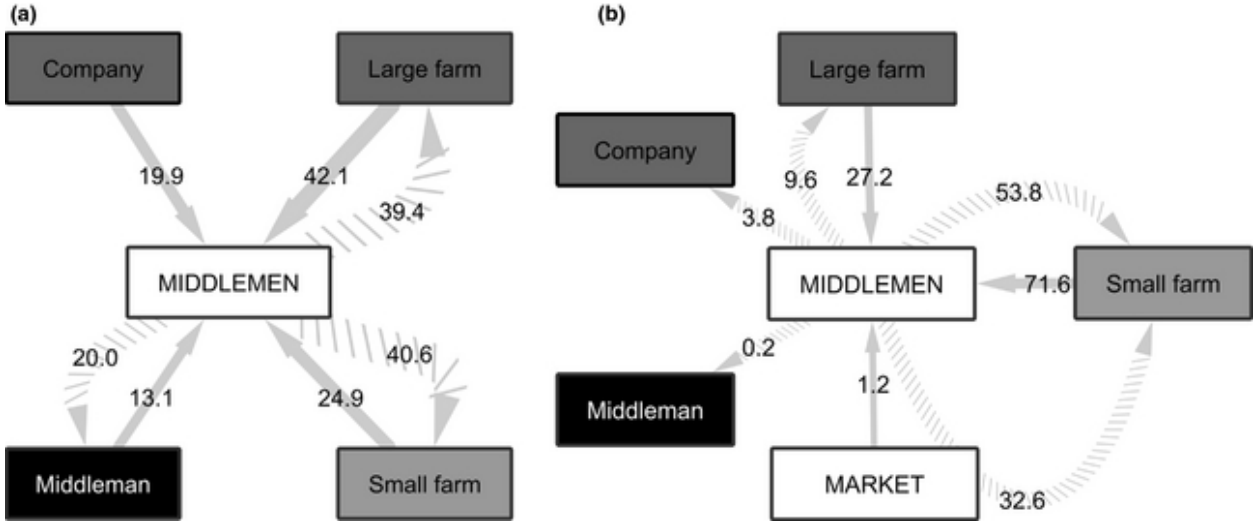

Figure 4 Spatial distribution of the pig movements generated by interviewed farmers and traders

The number of pigs purchased in and sold to a province is represented on the overall map of Vietnam, and in a zoom of the RRD. The number of pigs exchanged within the same province is shown in a second zoom of the five provinces in the RRD where internal trades were mentioned.