4thICAAAE 2013 SEPTEMBER 22-25, Hammamet Tunisia
4th International Conference of the African Association of Agricultural Economists
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Insights from social network analysis are helping to build understanding of African Swine Fever epidemiology

Jacqueline K. Lichoti, Jocelyn Davies, Edward Okoth,
Yiheyis Maru, Richard Bishop

Invited panel session sponsored by the International Livestock Research Institute (ILRI) through the CGIAR Research Program on Policies, Institutions, and Markets (PIM)

"Network Analysis Applied to Livestock Value Chains: Relationships beyond Demand and Supply and Their Contribution to the Impact of Upgrading Interventions"

Insights from social network analysis are helping to build understanding of African Swine Fever epidemiology

Jacqueline K. Lichoti[1], Kenya Ministry for Livestock Development; Jocelyn Davies, CSIRO Ecosystem Sciences; Edward Okoth, International Livestock Research Institute and Biosciences eastern and central Africa; Yiheyis Maru, CSIRO Ecosystem Sciences; Richard Bishop, International Livestock Research Institute and Biosciences eastern and central Africa

Abstract

Pig movements are likely to play a signficant role in the spread of important infectious diseases such as the African Swine Fever. Characterization of movement networks from farm-to-farm and through other types of farm or household operations can provide useful information on the role that networks play in acquiring and spreading infectious diseases. Analysis of social networks that underpin these pig movements can also reveal structures that are important in the transmission of disease, trade of commodities, the spread of knowledge and norms of social behavior. Our study assessed pig movements among pig keeping households within Kenya and Uganda and across the Kenya-Uganda border to help understand within country and trans-boundary pig movements.Villages were sampled using randomized cluster design. Data was collected through interviews in 2012/13 of 683 smallholder pig-keeping households in 38 villages. NodeXL software was used to analyze pig movement networks at village level. Movement of pigs occurred through agistment, sow service, restocking of household pigs and sale of finished pigs for slaughter. Most sow services occurred within the same villages or villages that were close by. Cross-border boar service between Uganda and Kenya was also recorded. Internal and unmonitored trade in both directions was prevalent. Most pig sales during ASF outbreak were to traders or other farmers who were most likely not coming from the same village. Close social relationships between actors in pig movement networks indicate the potential for possible interventions to develop shared norms amongst smallholder pig keepers to manage risk of ASF contraction and transmission.

[1] kasiiti.orengo@gmail.com

Introduction

Epidemiological research began to engage with social network analysis (SNA) in order to address recognized inadequacies, highlighted by HIV-AIDS, in representing the social structure of populations and patterns of social interaction through which infective agents spread (Klovdahl et al. 1994). While the long established equation-based approach to epidemiology, built on the SIR model (S-susceptible, I-Infected, R -Recovered), provides rigorous results given sufficient data on variables affecting infection and recovery rates, it does not provide for analytical treatment of complex scenarios with multiple transmission pathways and incomplete or uncertain knowledge of transmission risks and rates (Skvortsov et al. 2007). Epidemiological research has engaged with SNA to develop better predictive models of disease transmission and inform effective strategies for intervention and control (Klovdahl et al. 1994; Woodhouse et al. 1994; Rothenberg et al. 1998; Martinez-Lopez, Perez, and Sanchez-Vizcaino 2009).

SNA is proving to be an important tool for identifying paths for transmission of infectious diseases amongst livestock. Much of the risk of livestock disease spread is associated with animal movements, which are amenable to analysis using social network tools. The first subtantial application of SNA in an animal disease context was ex-post investigation of how the 2001 UK Foot and Mouth Disease outbreak spread. SNA has since been used at a much smaller scale to examine spread of Hendra virus in Australia, to characterize likely spread of cattle and pig disease in Denmark, and the spread of Avian influenza in China. Use of SNA in preventative veterinary medicine also appears to be expanding, being used to identify populations and areas at risk for disease introduction and dissemination (Martinez-Lopez, Perez, and Sanchez-Vizcaino 2009).

SNA is also increasingly being applied to understand the diffusion of information through interpersonal communication, such in promoting preventative health behaviours (Valente and Fosados 2006). Such research builds on the recurring view within public health domains in particular (Porter 1999), also applied in association with product marketing (Peres, Muller, and Mahajan 2010; Langley et al. 2012), that attitudes, beliefs and behavious are transmitted between people much like communicable diseases, through a process of social contagion (Christakis and Fowler 2013). While social contagion does not explain all processes of adoption of innovation or social change (eg (Alvergne et al. 2013) it does highlight that the social networks that will be important in livestock disease control are not only those related to livestock movements but also those that influence people's adoption of attitudes and behaviors that could reduce the risk of disease transmission.

The social network research reported here is part of a larger study conducted by BecA-ILRI in partnership with CSIRO as part of AusAID investment directed at sustainable improvement in food security in sub-Saharan Africa. The larger study aims to understand the epidemiology of African Swine Fever (ASF) as a basis for improving prevention and control of ASF outbreaks and for reducing social and economic impact of the disease on pig value chain actors. The study focuses on pig keeping by smallholder African farmers and ASF impacts on these farmers and on other actors who are engaged in the very localised value chains that characterise most smallholder pig production. Empirical research has been conducted in the border region of Kenya and Uganda because this area has been identified Department of Veterinary Services Kenya as a priority region for understanding the ASF transmission dynamics due to frequent recent outbreaks and risks of transboundary transmission.

Pork production is increasing in certain African countries, particularly Uganda (pig population 3.7 million) and Nigeria (pig population > 5 million). Western Kenya's recent annual growth rate in pig meat production was 7.4%, higher than that of other types of meat in the country (Kagira et al. 2010). ASF is widely regarded as representing the major disease constraint to pig production and enhancement of pork value chains in Africa (Costard *et al.*, 2009). AU-IBAR statistics estimated 260,000 pig deaths in sub-Saharan Africa in 2009 (0.65% of pig populations), but this is certainly a minimum figure due to under-reporting of disease outbreaks.

The causal agent for ASF is a large DNA virus classified in the monotypic family *Asfaviridae*., genus *Asfivirus* (Dixon *et., al*. 2005). African Swine Fever is highly contagious amongst pigs and is easily spread over broad geographical areas through the movement of infected pigs or contaminated pork. Transmission and maintenance of ASFV can occur in a sylvatic cycle and/or in a domestic pig cycle. A range of wild and domestic pig species are susceptible and different tick vector species can be involved. In Eastern and Southern Africa, soft ticks and warthohs are involved in the sylvatic cycle. The role of another wild suid, the bush pig (*Potamochoerus larvatus*) remains uncertain (Jori and Bastos 2009). In endemic areas, spread at local level is often associated with free-ranging pig production, local pig movements and lack of basic biosecurity measures (Solenne et.al.,2009). The specific causes of ASF outbreaks are difficult to pinpoint because of the multiple factors that affect transmission.The virus can cause 100% mortality when introduced into a naïve pig population, such as occurred when the pig population of Cameroon was decimated in 1982 (reviewed by Penrith *et al.* 2004). Later there may be sporadic recurrence of smaller scale epidemics.

There is currently no vaccine and ASF control is by diagnosis and slaughter to eradicate infected animals. Biosecurity is the main option for prevention of outbreaks, and is absent on almost all small holder farms. African swine fever (ASF) causes serious socio economic losses to the pig value chain actors and has threatened the livelihoods of these actors in terms of poverty alleviation and food security (el Hicheri et al., 1998; Nana-Nukechap and Gibbs, 1985; **Martínez-Avilés (2009**). African Swine Fever outbreaks have threatened export of pig products from Kenya thus lowering foreign exchange earnings (DVS, 1994-2012). Control measures in Kenya have been instituted including public awareness on proper husbandry methods and pig and pig products movement control. All these measures have not curbed the spread of ASF.

We have aimed to characterise the structure of networks through which pigs are traded in our study region in order to identify (1) potential pathways for transmission of ASF virus, and (2) structural characteristics that might be engaged in interventions aimed at reducing the risk of ASF transmission and at enhancing pork production. This paper describes networks of pig movements associated with trade, boar service and agistment along the Kenya-Uganda border.

Methods

Data were acquired through interviews between July & December 2013 of respondents from 683 smallholder pig-keeping households in 38 villages within Tororo and Busia Districts, Uganda and Teso and Busia Districts, Kenya. Villages were the primary sampling units and households (in selected villages) were the secondary sampling units. Village houses/households are not spatially clustered in this region. Rather the houses and farm fields that are recognized as being part of the same village are relatively dispersed though all sampled households in a village were less than 1km from other sampled households in the same village. Two villages (ie. Level 5 admin units), each with >20 pig-keeping households, were randomly selected within four randomly selected Level 4 administrative units (i.e Kenyan sub-location; Ugandan parish) that formed part of four randomly selected Level 3 administrative units (ie Kenya location; Uganda sub-county) that each have a part of their boundary <25 km from the international border. The sampled villages are shown in Figure 1.

Figure 1: Study region showing sampled households in village clusters

We aimed to interview 20 pig keeping households in each village. Households were randomly selected from lists generated by village chiefs. If selected villages turned out to have markedly less than 20 pig keeping households, additional households from adjoining villages were randomly selected for recruitment. Within households we asked to interview the person who was available and who knew most about the households' pigs. An adult member of every household we approached agreed to participate in the interview and gave permission for blood, serum and faecal samples to be taken from their pigs.

To enable analysis, networks need to be carefully defined with clear rules about the nature of nodes, the definition of a tie (also known as an arc or edge) between nodes and the strength of tie (McAllister et al paper). In the graphical representations included here we define a node as a cluster of households within the same village. That is, although data were collected at household level, our analysis here is aggregated to village level. We define a tie as the movement of a pig between nodes such that tie strength is a function of how many pigs moved between particular nodes.

The data collected that are most pertinent to SNA includes farmer's recollection of the source of pigs that were on the farm at time of survey and both the source and sink/fate of pigs owned during the previous year but no longer on farm. Farmers were asked about the type of relationship they had with the person from whom they bought or sold a pig (eg relative, neighbor, trader or butcher). Farmers were also asked to provide the name and location of the person they acquired each pig from and sold each pig to. Interviews also sought information on the timing of purchases and sale events, sources of inputs for pig keeping (eg feed, knowledge, health care), and the household's sources of advice, trust and credit related to pig keeping and to their broader livelihoods.

The preliminary analysis of pig movement networks presented here encompasses only some of the data set. NodeXL software has been used to visualize pig movement networks at village level to show network structures amongst villages, rather than individual households.

Limitations of the data set include that it cannot capture the full structure of all the pig movements in the study region, but only the ego-networks of the sampled households. While this limits the completeness of our understanding of the potential pathways for ASF virus transmission through pig movements in the study region, the data are nonetheless a valuable basis for inference about the overall structure of the networks of pig trades and other pig movements in the region. Indeed, SNA methodologies recognise that valid inference about network structures is the goal and that data about the networks of particular nodes in the network (here, households) may be incomplete and/or inaccurate (Klovdahl 2005)

Analysing the pig trade and movement data geospatially remains a challenge. While interview data includes farmers estimate of the distance from their home to households that that they moved pigs to or from, we have not yet been able to establish geo-spatial locations for most of the villages that were named by farmers but not actually surveyed by us.

Results

Pig Purchases

Figure 2 shows the pig purchasing networks amongst sampled villages in Kenya and Uganda over the 12 month period prior to each interview. Sampled villages are represented by the vertices that are located at the centre or hub of the various network components and circled arrows around these vertices ('self-loops') indicate pig purchases between households within that village. Other arcs or ties are unidirectional, since they represent pigs purchased at other villages and brought to households in the sampled village.

Households tend to purchase pigs from within the same village or a nearby village. Purchasing of pigs occurs across the Kenya-Uganda border, as indicated in Figure 2: households in two Kenyan villages had purchased from Uganda (Figure 2a) and households in seven Ugandan villages had purchased from Kenya (Figure 2b, villages of Kadanya, Alupe, Bwolia A, Bwani, Okame Amagoro, Nebolola B and Bulekya). The extent of cross-border purchase may prove to be greater when the geospatial location of villages named by sampled households as pig sources, but not sampled, is established.

Figure 2a also indicates that two villages in Kenya, Amoni (top left quadrat) and Akiriamas (bottom right quadrat) have the character of hubs, in that they supplied pigs to several of the sampled villages. Notwithstanding the prevalent pattern of purchase from nearby villages, the small number of components in each diagram is remarkable, particularly since the sampled villages are only a small proportion of the villages in the study area, span 70 km in a north south direction and 30 km east-west (see Figure 1), and most pig trades and other movements are less than 5km..

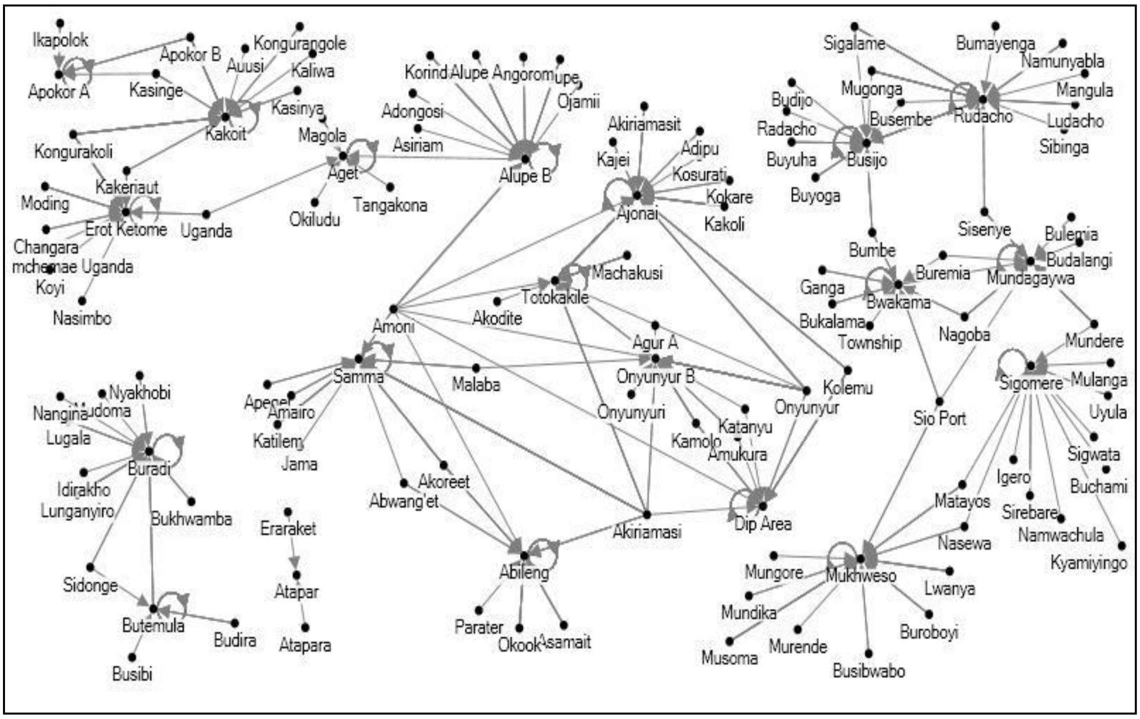

Fig 2(a)

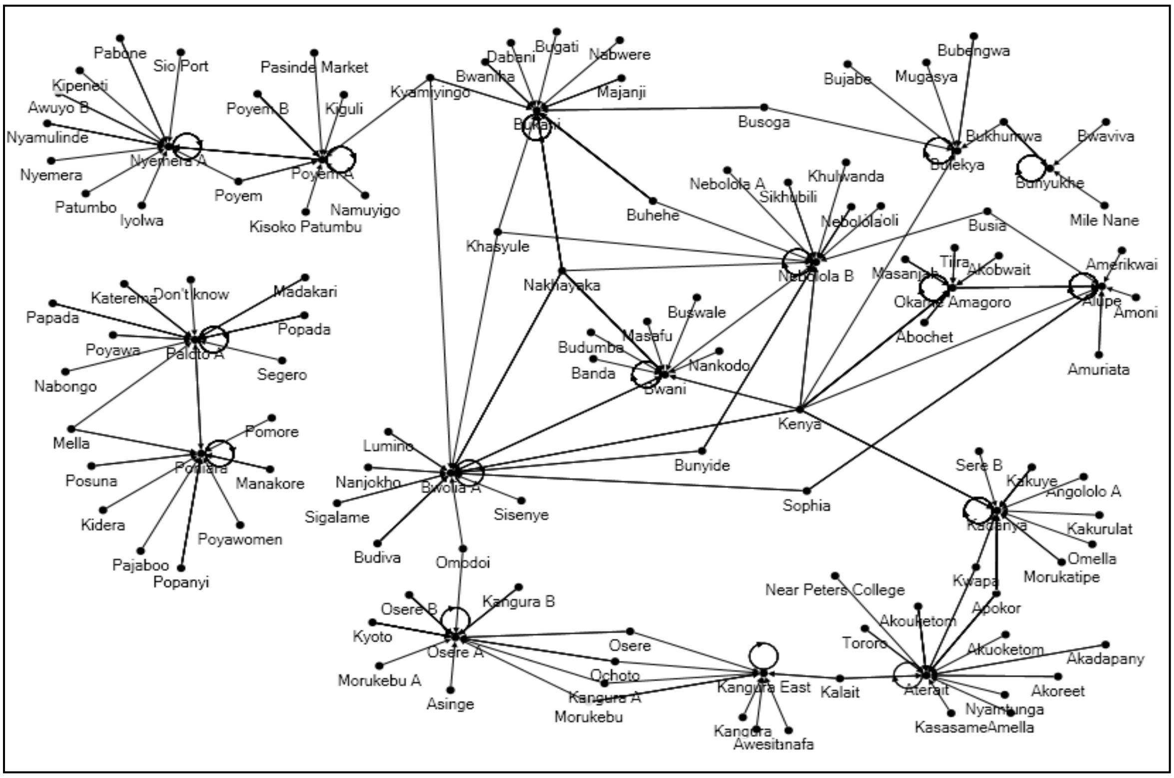

Fig 2(b)

Figure 2. Pig purchases by sampled households in (a) Kenya and (b) Uganda over 12 months in 2011/12, aggregated to show households in the same village as a single node. Note: The graphs are aspatial. Edges are not weighted for number of pig purchases. Arrows shows direction of movement of pigs and an arrow that circles around a node ('self-loop') depicts trade within village. The nodes labelled "Uganda" in Figure 1 and "Kenya" in Figure 2 indicate the source of pigs that farmers said were traded across the international border. Further cross border trades may be revealed when the location of villages not actually sampled is established.

Agistment of pigs

Substantive movement of pigs takes place through agistment. Households agisted pigs due to several reasons; feed and labour constraints, to initiate pig keeping where there was no start-up capital and during disease outbreaks to avoid infection of clean pigs, feed constraints on their own farm, when there is nobody in their own household to take care of the pigs, when another household wants to try pig keeping but lacks finances to purchase pigs and also as a strategy to protect pigs from infection during outbreaks of disease, including ASF. Of the Kenyan households (363 households) sampled, 21% had pigs agisted within/out of the households while Uganda (320 households sampled) had 45.6%. Figure 3 shows the agistment networks with the width of arrow representing the number of pigs agisted in and out of the village in the 12 months prior to interview. Most agistment was between households that were familiar with each other and located within 5 km of each other, often within the same village as indicated by the self-loops at sampled villages in Figure 3.

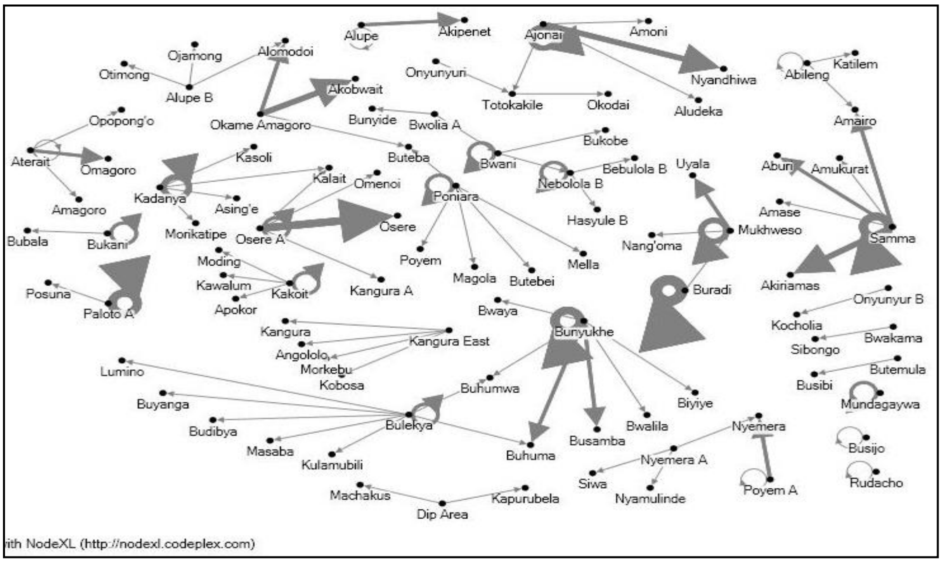

Figure 3. Pig agistment networks of 38 sampled villages in Kenya and Uganda

Boar service

Pig movements occur within and between villages for service of sows, as indicated in Figure 4. Some cross border service was recorded in that boars that serviced sows in Apokor A village in Kenya (top-centre in Figure 4) were reported by sow-owners to have come from Uganda more than 10 Km from the house hold. (without further specifics about location indicated)[2].

Among the households sampled that had a sow serviced in the 12 months prior to interview, 86% (211 out of 245) knew the household that owned the boar. Nearly three quarters of these households (73%) borrowed a boar for service. The boar is either taken to the sow or the sow moves to the boar owners' household for a minimum of 2 weeks (to be sure that service has occurred). Freelance service, in which the sow and boar mated while free-ranging (pigs that are not confined), was reported by12% of households.

13% of the households owned boars that serviced the sows i.e 33 (19 Kenya and 14 Uganda)

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[2] Other cross-border service may become apparent when all the villages named in Figure 5 are geo-located.

The number of entire boars from the sampled villages were 44, 19 (from 16 households) from Uganda and 25 (from 25 households) from Kenya. The total number of sows in the households interviewed were 148 in Kenya and 136 in Uganda. The boar to sow ratio in the Kenyan household/pig sample was 1:6 while in Uganda it was 1:7. In both cases this greatly exceeds the recommended boar:sow ratio, which is 1:20 (Greg & Graema (2006). Nevertheless, 16% of interviewees said that the lack of boars to service pigs was a constraint on pig production.

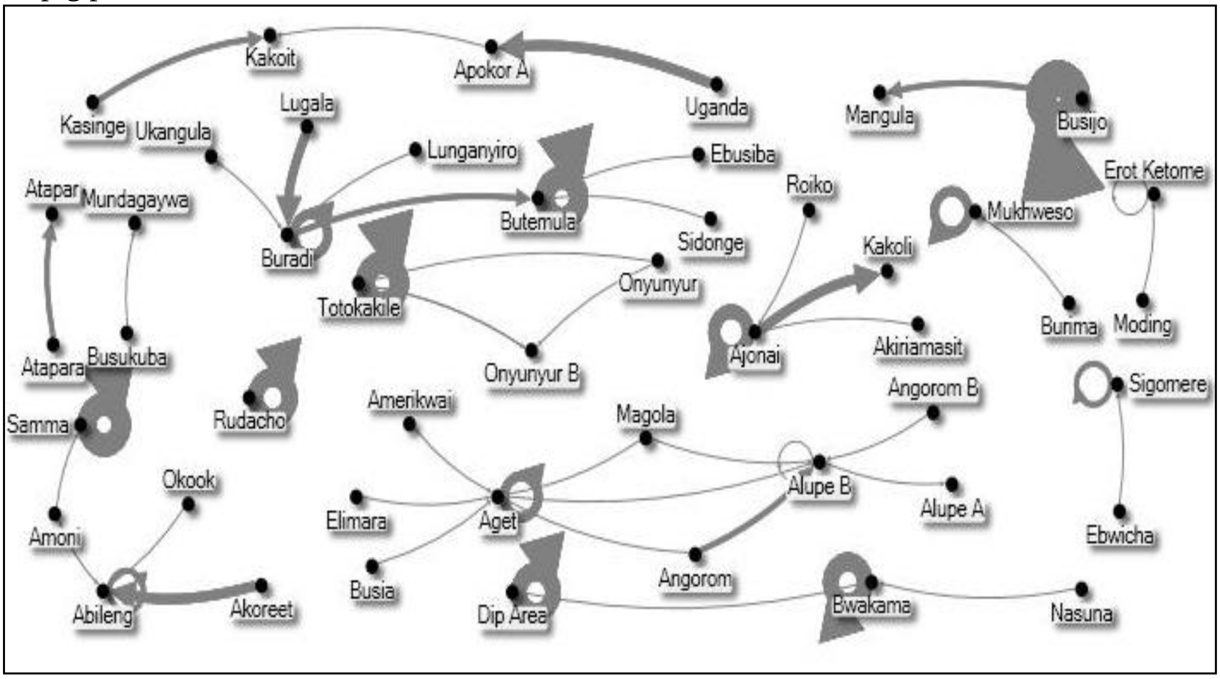

Figure 4: Pig movements for boar service between sampled villages in Kenya and Uganda

Pig sales

Among the households interviewed (683), 187 in Uganda and 341 in Kenya had sold pigs during the previous year. Some households didn't provide information on where they had sold their pigs (15.5% (29) in Uganda and 12.3% (42) in Kenya). More households from Kenya purchased pigs from Uganda than Uganda households purchased from Kenya.

Selling of pigs for slaughter occurred during ASF outbreaks in both Kenya and Uganda, and some households from both countries sold pigs across the international border during outbreaks. Sales to people who the household did not know were more prevalent during outbreaks Coloured arrows (edges) in the graphs of pig sales, Figure 5 represents the pig sales/sink networks of villages where some household interviewees said they had sold pigs at the time of an ASF outbreak during previous 12 months. Interviewees in six of the 18 sampled villages in Kenya reported such sales and two households in these villages said that they sold pigs when an ASF outbreak was on their farm. All the pigs sold by Kenya households during outbreaks were to traders that came from outside the selling household's village.

Household interviewees in ten of the 16 villages sampled in Uganda reported they had sold pigs during ASF outbreaks in their vicinity, and five reported they had sold their pigs when the outbreak was on their farm. Households in one village, Poyem A sold pigs sold within their own village at the time of an ASF outbreak. Two households said they had sold to a relative. Ten households had sold to a trader in a different village.

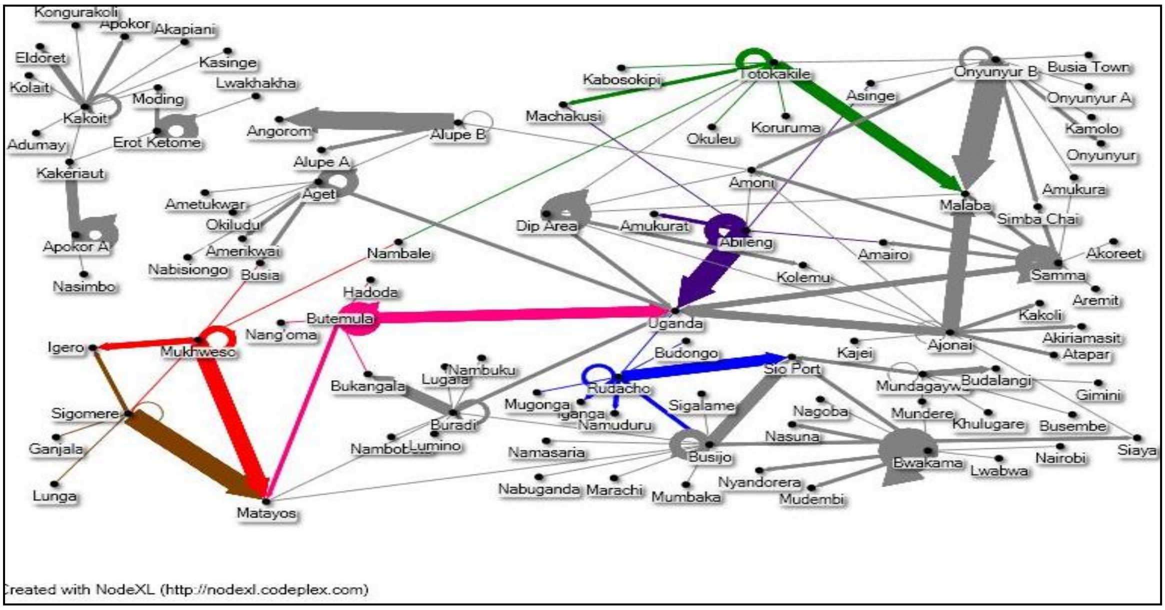

Fig 5(a)

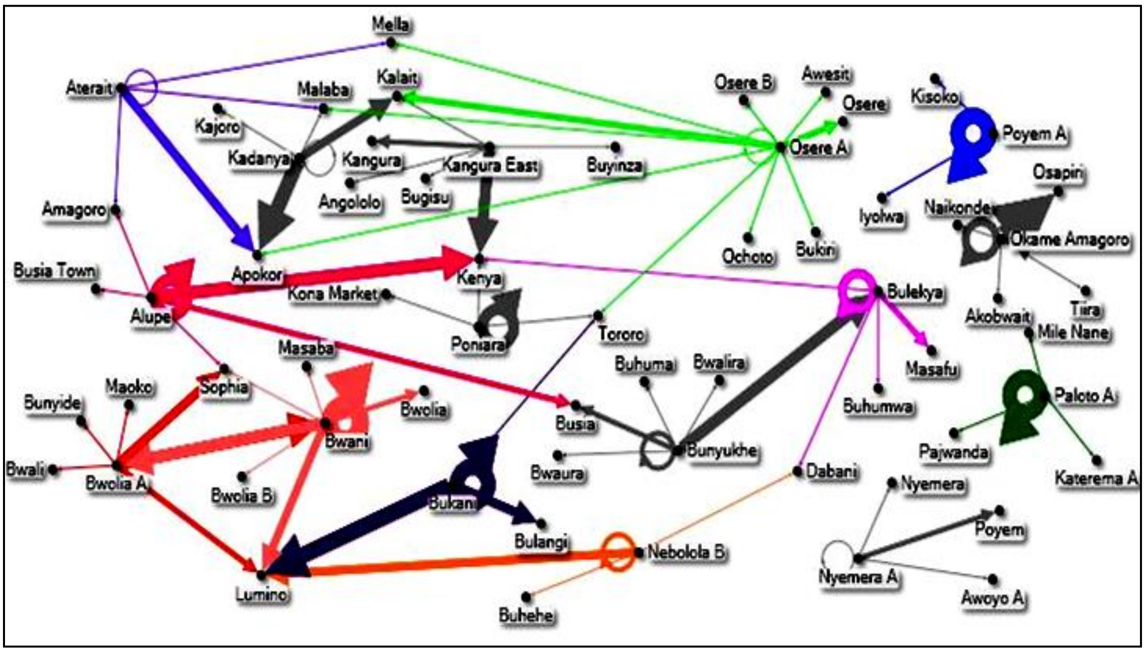

Fig. 5(b)

Figure 5: Sales of pigs from sampled villages in (a) Kenya and (b) Uganda. Width of arrows indicates number of pigs sold; coloured lines indicate the sales networks of villages where some households said they sold pigs during ASF outbreaks (but not all the sales represented by coloured edges were made during ASF outbreaks).

Discussion

Although most pig trade in the Kenya-Uganda border region is very localized, pig trade and other pig movement networks link widely spaced villages. Our data shows a high degree of pig movement between households in the same village and to nearby villages as well as unmonitored movement of pigs across the international border.. The households interviewed generally sold their pigs to known persons, but in an ASF outbreak scenario, they would sell to persons unknown to them and from a far off village. There is reduced risk of repurcussions on the seller of a sick pig if sales are to strangers in relatively distant places. In addition, sales within their own village may not be possible because other people would be aware of the outbreak and would not buy. However other mechanisms may spread ASF outbreaks within villages, including contact between free-ranging pigs and dense foot traffic of people walkign around the village area, which can lead to ASF virus being spread on feet, foorware or clothing.

Sale of pigs for slaughter during outbreaks is a coping strategy for farmers, circumventing the risk of the pig dying and the household being unable to realise the value of their asset. However it is also a behaviour that can readily spread outbreaks since the virus can be transmitted to other pigs if they contact undercooked meat, offal and slaughter waste from infected animals. Virus spread may also be through tools used during slaughter, items used to transport infected animals, footwear and clothing.

Social /physical proximity in the value chain, as happens when buyer and seller are known to each other, and in the same local area, increases the likelihood that both parties will act to look after each others' interests. Thus these localized value chains may offer a strong foundation for collective commitment to biosecurity actions to prevent ASF being spread into an area. Public awareness campaigns about the disease and publicity about suspected outbreaks may help contain outbreaks because most households that sold pigs during an outbreak never did so to nearby their own village or nearby villages. They may have done this most likely due to the fact that the nearby households may have known there is a disease outbreak or they may face negative consequences if it is discovered that they sold diseased pigs. However, given that other data from our study indicates that supply of pigs for slaughter often falls short of demand in our study region; farmers whose pigs fall sick with ASF are likely to continue to be able to find distant buyers. Sales to socially and spatially distant actors will bypass localized social sanctions while potentially spreading outbreaks to distant locations. Effective institutions at deeper levels with robust cross-level linkages will also be required to manage this broader risk. These will need to encompass incentives for ASF reporting by farmers, butchers and other traders, and timely action to contain pig movements to prevent outbreaks spreading. Understandings of the structure of the various networks through which pigs are traded will be applied in the development of options for institutional change for more effective management of ASF risk.

Conclusion

The study revealed several networks;agistment of pigs to and from household, purchase of pigs for rearing, boar service and pig sales. All these movement networks can play a critical role in spread of ASF, particularly those from or through hubs. The study found that agistment and sales movements can be initiated to reduce risk and losses from ASF at a farmer household level but can spread the disease with unintended negative impact of outbreak at a broader community and cross border levels. In presence or rumors of disease outbreaks, a different pig sales behavior has been displayed, where pigs are sold to strangers from more distant places, which can result in spreading of ASF further. However, the study also revealed that most of the pig movements for different purposes are within short distances, among households with close social networks that most likely to share norms of trust and reciprocities. Incentives that encourage disease reporting rather distress selling to strangers as well as measures that take account of the characteristics of pig movement networks and underpinning close social ties are important for more effective ASF risk management.

Apart from pig sales, disease spread can also take place through sow service and agistment. During quarantine these practices continue because they are not addressed as some of pathways through which disease can spread.

During the study, it was also observed that within the villages, households are linked through non official pathways. Because of the free ranging a tethering production systems, people using these pathways carry infected feaces or infected waste on their shoes and spread disease to pigs in other households. Public awareness on how ASF spreads is very important because it is widely known that the disease is spread through bringing home infected pork.
Close relationships between actors in pig movement networks indicate the potential for possible interventions to develop shared norms amongst smallholder pig keepers to manage risk of ASF contraction.

Acknowledgements
We thank the Australian Agency for International Development (AusAID) for supporting this research and the partners who manage the research program: CSIRO and the Biosciences East and Central Africa (BecA) Hub at the International Livestock Research Institute, Nairobi. We are grateful to pig keeping households in Kenya and Uganda for contributing information that has helped build our understanding, to the many members of the ASF project team who helped to collect the data; and to Tracey May (CSIRO) for data management and preparation of Figure 1.

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