Preventive Veterinary Medicine 118 (2015) 293–305

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Analysis of pig movements across eastern Indonesia, 2009–2010

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ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 20 October 2014
Accepted 2 December 2014

Keywords:
Smallholder farmer
Social network analysis
Pigs
Eastern Indonesia
Biosecurity
Classical swine fever

ABSTRACT

Knowledge of live animal movement through markets and from farm-to-farm is needed to inform strategies for control of trans-boundary animal diseases (TADs) in south-east Asia, particularly due to consumer preference for fresh meat. In eastern Indonesia a TAD of principal interest for control is classical swine fever (CSF) due to its impacts on smallholder farmers. Pig movement is considered a contributor to failure of current CSF control efforts but pig movement patterns are not well understood. This study investigated movement of live pigs in West Timor, Flores and Sumba islands during 2009–2010, with the aim of informing CSF control policies for Nusa Tenggara Timor province. A market survey of 292 pig sellers and 281 pig buyers across nine live pig markets and a farmer survey across 18 villages with 289 smallholder farmers were conducted and information collected on pig movements. The data obtained was used for social network analysis (SNA) on formal (via a market) and informal (village-to-village) movements using information on trading practices, source and destination locations, and the number of pigs being moved. Both inter- and intra-island movements were identified, however inter-island movement was only observed between Flores and Sumba islands. West Timor and Sumba had highly connected networks where large numbers of villages were directly and indirectly linked through pig movement. Further for West Timor, both formal and informal pig movements linked the capital Kupang, on the eastern end of the island to the western districts bordering East Timor connecting all five districts and demonstrating that informal movement transports pigs over distances similar to formal movement on this island. Sumba had a higher potential for pigs to move to a greater number of sequential locations across the entire island. Flores was found to have a more fragmented network, with pig movements concentrated in its eastern or western regions, influenced by terrain. Markets were confirmed as high-risk locations for the introduction and spread of disease, having over 20 contacts (based on in- and out-degree values) depending on operational day. Villages considered high-risk for CSF spread via informal movements were characterised by higher volume of pig exits and/or linkage to higher numbers of other villages. These findings demonstrate that informal movement (often related to cultural practices) can be extensive and the high level of connectivity dictates that control strategies for CSF and other highly transmissible diseases must be formulated at the provincial level and in collaboration with East Timor.

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http://dx.doi.org/10.1016/j.prevetmed.2014.12.002
0167-5877/

1. Introduction

Animal movement, with aggregation of animals for transport and at markets and transfer of infected animals between locations is able to spread infection to previously non-infected populations and to increase pathogen load in infected populations, has long been recognised as an important contributor to infectious disease dispersal (Bigras-Poulin et al., 2006; Noremark et al., 2011). Trade in live animals, therefore is a challenge for the control of trans-boundary animal diseases (TADs) and is higher risk for pathogen spread than trade of chilled or frozen meat. Consumer preference for freshly killed meat in south-east Asia necessitates the movement of live animals to slaughter points close to consumers (Deards et al., 2014) and is a feature of the livestock market chain that runs counter to effective disease control. Thus knowledge of the reasons for and of the frequency and extent of live animal movement underpins the development of strategic plans to control infectious animal diseases at district, province and national levels in this region.

In smallholder livestock systems animal movement is often localised and related to sale for cash income. However, smallholder herds can contribute to extensive livestock trade as demonstrated by large ruminant trade in the Greater Mekong Sub-region. An established network of traders has been identified sourcing cattle and buffalo from villages in Cambodia and Laos and moving them between provinces and countries for slaughter in regional cities in response to consumer demand (Kerr et al., 2012). Delineation of this trade network has consolidated agreement that a regional approach involving several countries is essential for effective control of TADs such as foot-and-mouth disease (Cocks et al., 2009).

Pork demand in the cities/larger centres of Cambodia and Laos is met by small-scale intensive farms that import piglets from Thailand and by smallholder semi-intensive farms across various provinces. Thus pigs for slaughter are sourced and moved by foot, motorbike and truck from farms and markets by local collectors collaborating with traders (Kerr et al., 2012). In the Philippines, smallholder semi-intensive farms raise most of the national pig population and traders source pigs for slaughter daily from multiple farms via well-developed networks that according to Alawneh et al. (2014) operate across provinces to supply demand at regional level, at least in central Luzon. The extent of contact between farms arising from this marketing network is recognised to have contributed to the rapid dispersal of highly pathogenic porcine reproductive and respiratory syndrome across Luzon in 2007 (Resontoc, 2009). It is evident from these examples of extensive pig market chains that, compared to the situation with predominantly local pig movement where disease control can focus on districts with clinical disease, knowledge of pig movement is needed to develop and implement appropriate biosecurity and disease control programmes at the province or island level.

In Indonesia pig production is dominated by the smallholder sector (Liano and Siagian, 2002; Christie, 2007) with pigs kept as a form of financial security and traded to generate supplementary income (Christie, 2007; Leslie, 2012). The province of Nusa Tenggara Timur (NTT), in eastern Indonesia, has the largest pig population, estimated at 1.8 million animals (Dinas Peternakan Propinsi, 2014). Around 85% of all households own at least one pig and keeping pigs is linked to cultural traditions. As pork is not consumed on a daily basis but more for celebratory events with preference for fresh meat, pig trade is imperative in this province to meet the high demand for live pigs to be slaughtered during social and cultural events, and transportation and storage of pork is minimal due to limited cold chain facilities (Johns et al., 2009; Leslie, 2012). This has led to the development of both formal trade movements through markets and informal trade transactions directly between villages, both of which are poorly documented and thus the implications for disease control are not understood.

For Indonesia, classical swine fever (CSF) is the priority disease for national control planning among the swine infectious diseases of concern (which include CSF, porcine reproductive and respiratory syndrome (PRRS), *Taenia solium* cysticercosis and swine influenza) (Ministry of Agriculture, 2013). Introduced to Indonesia in 1994, with the first confirmed case in North Sumatra (Hutabarat and Santhia, 1999), CSF is now an endemic disease across most of the country, with little to no control implemented in the smallholder sector. From national and provincial perspectives, NTT province is a target area for CSF control. CSF was introduced to NTT province in late 1997 when pigs moved from East Timor to West Timor led to severe pig losses from 1997 to 2000 (Hutabarat and Santhia, 1999; Christie, 2007) and the endemic cycle of infection continues to substantially limit pig production today despite provincial government attempts to control it. Within NTT province, districts are recognised as either CSF infected or non-infected and there is a movement restriction which prohibits pig movements from infected to non-infected districts. However, the movement restriction and annual vaccination in areas with higher levels of reported cases are not achieving effective control. Pig movement is considered an impediment to control but pig movement patterns are not well understood and this knowledge gap prohibits targeted control activities. The close proximity of eastern Indonesia to Papua New Guinea and Australia represents a risk for spread to these CSF-free countries and reflects a regional interest to support improved CSF control in NTT.

The objective of this study was to describe the movement patterns of pigs both formally (village-to-market) and informally (village-to-village) across NTT province in eastern Indonesia. We used social network analysis (SNA) to describe the network contacts and topology to identify key village and market locations that are of a greater risk for spreading CSF virus through the market chain and to investigate the extent of formal and informal contributions to pig movement in this province. SNA, which has been increasingly applied in animal health over the last decade by investigating the connectedness and spatial structure of an animal movement network, aids identification of the locations with the greatest potential for disease spread (due to, for example, high throughput of animals or delivery of animals to many locations or distant locations) that can be targeted for surveillance or implementation of biosecurity (Christley et al., 2005; Natale et al., 2009).

2. Materials and methods

2.1. Study site and population

Nusa Tenggara Timur province (Figs. 1 and 2) is an archipelago comprising 566 islands with a total land area of 47,349 km^2 (only 2.5% of Indonesia's total). The province is divided into 21 districts. The three islands incorporated in the study (West Timor, Flores and Sumba) make up 17 of those districts. Data about live pig movements were collected from two surveys, a repeated market survey and a farmer survey (Leslie, 2012). Market respondents included pig sellers and pig buyers at the market place. For the pig farmer survey, those interviewed had been pre-selected from a sampling frame of pig raising households in 18 randomly selected villages (Fig. 2).

2.2. Movement data

The repeated market survey conducted at 9 markets sites collected data on formal pig movement from 292 pig sellers and 281 pig buyers for one market day during a high-demand period (September) and a low-demand period (November) in 2009. Markets were selected purposively based on three selection criteria: (1) large numbers of pigs being moved through the market (>20 on a selling day); (2) markets located in Flores, Sumba or West Timor; and (3) local expert opinion (Provincial Livestock Animal Health Department) which classified markets by importance. A total of 32 interviews were conducted at each market site across two interview rounds. The target was to interview a minimum of 50% of sellers present at market that day. Total seller and buyer numbers were also estimated to demonstrate the proportion of which those interviewed represented. The primary information utilised from this survey and incorporated into the SNA analysis were pig-source locations and destination locations (district and village levels), the number of pigs being moved to and from market and the number of sources utilised to obtain pigs. These movements were classified as formal: movement of pigs between villages involving sale/purchase at a market, and movement of pigs between islands entering and exiting via formal ferry ports.

A farmer survey conducted in 18 randomly selected villages collected data on informal pig movements over the previous 12-month period (2009–2010) from 289 households. Districts were selected purposively according to their CSF status and high rate of pig movements across West Timor, Flores and Sumba islands, with information provided by the Provincial Livestock Animal Health Department. Subdistricts and villages were then selected randomly. Following village selection, a sampling frame was developed by obtaining a list of pig owners and their pig herd size from each Village Head (*Kepala Desa*). Interviews of farmers with the largest herds were conducted; these farmers were found to be more likely to trade outside their village. The information utilised from this survey and incorporated into the SNA analysis included pig source and destination locations (village locations), number of pigs entering and leaving their herd and the reason for a pig entering or exiting their herd. Reasons for pig exit from a herd included whether the pig was sold, given as a gift or given to relatives/family members. For pigs entering a herd, this was classified as purchased pigs and those received as gifts. These movements were classified as informal i.e. movement of pigs between villages not involving sale/purchase at a market and movement of pigs between islands not entering and exiting via formal ferry ports.

It should be noted that data collected reflects different time periods. Market survey interviews recorded pig movements on one market day during a high-demand period and one market day during a low-demand period. Farmer survey interviews recorded pig movements events across a 12-month period (2009–2010).

2.3. Data management and analysis

Data from a farmer survey (Leslie, 2012) and a repeated market survey (Leslie, 2012) were initially entered into databases designed using the computer program Epi Info^{TM} Software (Version 3.5.1, CDC, www.cdc.gov/epiinfo, Atlanta, GA, USA). Data were then exported to Microsoft Excel (version 12.0, Microsoft Corporation, Redmond, WA) in which purpose-built spreadsheets were developed to establish data and attribute tables for each data set: (1) seller network (A); (2) buyer network (B); (3) market network (C): seller and buyer data combined (i.e. A + B); (4) farmer network (D); and (5) a province network: market and farmer data combined (C + D).

A movement event was defined as the transportation of one or more pigs from an origin premises (village or market) to a destination premises (village or market). Contacts were defined based on the direction of their movement including, seller: source village to market destination; buyer: source market to village destination; and farmer: source village to destination village. To improve reporting accuracy for village locations, each respondent was required to state the district, subdistrict and village name for pig source and destination locations. These were then subsequently verified using the Provincial Animal Health Department Village List, a complete list of villages in NTT Province from 2008 and checked for consistency. Respondents that did not provide complete location information data, including village name, were excluded from analysis.

Data were then exported into a social network analysis program, UCINET (v6.137 Analytic Technologies Inc., Harvard, MA, USA), which allowed construction and analysis of the pig-movement networks. Subsequently NetDraw (Version 2.091, Graph Visualisation Software, Harvard, Analysis Technologies), a social network visualisation software, was used to develop graphic representations of the pig-movement networks.

Within the constructed networks, markets and villages were designated as nodes. These nodes were then connected by edges which represented the relationship between two nodes, in this case the volume of pigs being moved. The volume of pigs was selected as an edge weighting since data on the frequency of pig movement was not available from market interviews and was limited from farmer interview data. The origin and destination of each movement event was specified allowing a directed (asymmetrical) network to be constructed.

Fig. 1. Map of South-East Asia and Australia, identifying Nusa Tenggara Timur (NTT) province in eastern Indonesia; mapping data obtained from Hijmans et al. (2014).

The market network was considered as a 2-mode network; market and village locations were treated distinctly in which villages were not directly linked and pigs were required to move through a market node. Where appropriate, 2-mode normalised degree and density calculations were based on Borgatti and Everett (1997). The farmer and province networks were considered as 1-mode networks since pigs could move between either villages or markets. A common list of villages and markets was established among the three datasets by combining all villages reported to allow a complete network of the province to be developed. This was done by assigning an unique identification to every village and market reported across the networks. Correlation was investigated between in- and out-degree values by calculating the Spearman rank correlation coefficient (Microsoft Excel, 2007).

3. Results

The total number of individuals interviewed for the market study was 573 (Leslie, 2012). For seller respondents, a total of 260 individuals and for buyers a total of 262 individuals were included in the SNA. The removal of 51 (8.9%) respondents from analysis (19 sellers and 32 buyers) allowed complete location data to be analysed.

A total of 289 farmers were interviewed during the farmer survey (Leslie, 2012). Respondents were asked to provide details regarding pigs exiting or entering their herds during 2009–2010. A total of 133 farmers reported pigs exiting their herds and 111 reported pigs entering with only 32 (11.1%) farmers reporting two or more transactions during 2009–2010 and 64 farmers (22.1%) who undertook both actions. Ultimately, 180 (62.3%) farmers contributed pig source and destination location information to the SNA with 109 farmers not providing location information because there were no entries or exits to their herd.

3.1. Market network

The overall market network representing formal pig movements consisted of 307 nodes (Table 1), nine of which were market locations, while the remaining 298 nodes were reported village locations. When the seller and buyer networks were combined, there were 47 common villages identified. Sumba was identified as having the smallest overall network size. However, this network had the greatest number of directed links, highlighting a high level of connectivity across Sumba.

The diameter of the market network was eight. West Timor was found to have the highest diameter compared to

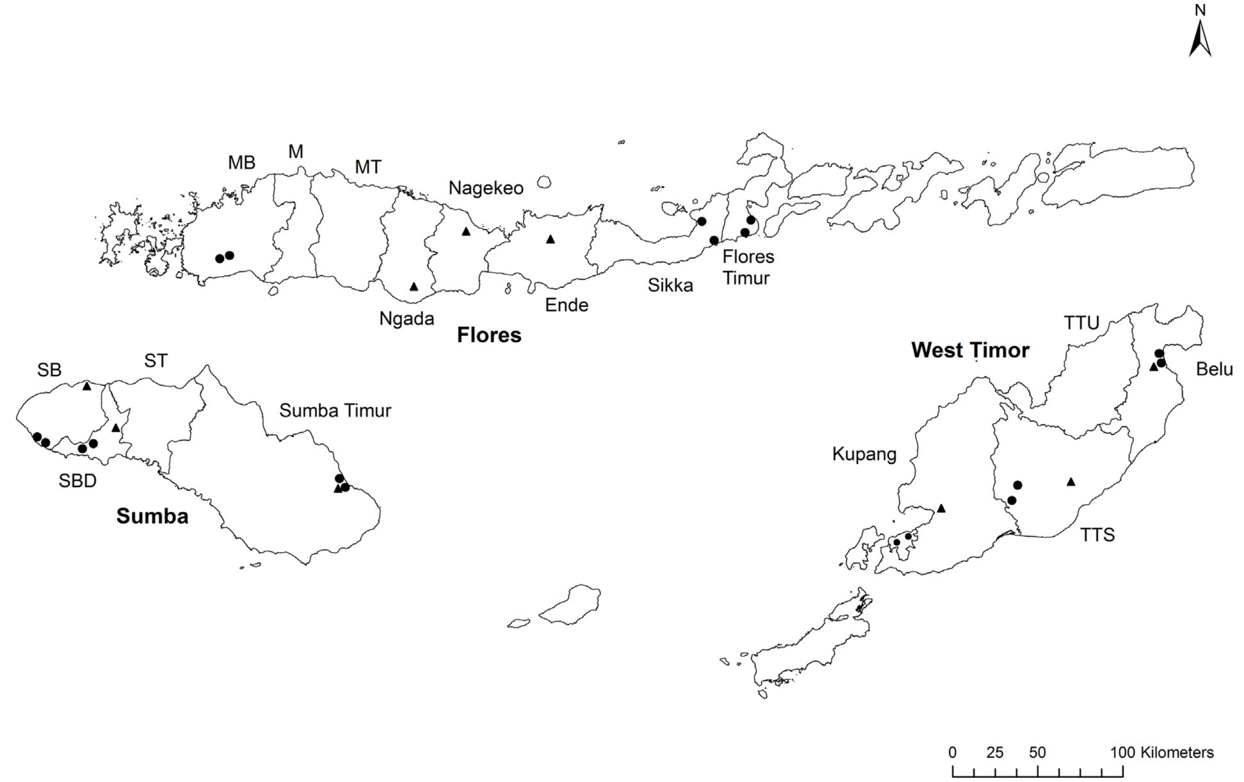

Fig. 2. Locations of market and village sites, black circles: 18 villages selected for survey; black triangles: 9 live pig markets selected for survey; bold text: island; non-bold text: district names; TTS: Timor Tengah Selatan; TTU: Timor Tengah Utara; MT: Manggarai Timor; M: Manggarai; MT: Manggarai Barat; ST: Sumba Timor; SBD: Sumba Barat Daya; SB: Sumba Barat.

the other islands (Table 1). The geodesic distance was similar across all market networks. Hence, for these networks, the majority of pigs were moved between 2 sequential nodes. The highest average geodesic distance was seen in West Timor with an average of three consecutive nodes. A total of 366 directed links were identified for the overall market network highlighting the potential for pigs to move to different districts of the province. Pig movements were identified from the capital of West Timor (Kupang) to the border of East Timor, connecting all five districts. Detusoko and Mbay Market on Flores and Waikabubak Market on Sumba had the highest 2-mode normalised out-degree, representing a high-risk potential to spread disease (Fig. 3 and Table 2). Two markets in West Timor (Camplong and Niki Niki Market) had the highest 2-mode normalised in-degree, demonstrating a higher risk potential of receiving pigs from an infected village. Pigs sold at Detusoko and Mataloko markets in Flores were found to travel to Sumba (Fig. 4). A positive correlation was detected between normalised in- and out-degree values for market locations (Spearman rank: $r_{SP} = 0.948$, $P < 0.001$, $n = 9$). In addition, Wetabula Market on Sumba had the largest volume of pigs entering and exiting a marketplace (Table 1). This corresponded with the finding that pig sellers and pig buyers present at Wetabula Market had the highest average number of pigs per seller coming to the markets (Leslie, 2012).

Two key villages in Sumba – Lumbukori and Rada Mata located in districts (*Kabupatens*) Sumba Timur and Sumba Barat Daya respectively – were found to have contact with all three live pig markets in Sumba involved in the study. In addition, comparisons were made regarding a high-demand period (September) and a low demand period (November). It was found that a higher-demand period did not necessarily result in contact with a larger number of villages. However, higher pig volumes were seen to move through the marketplace during this period.

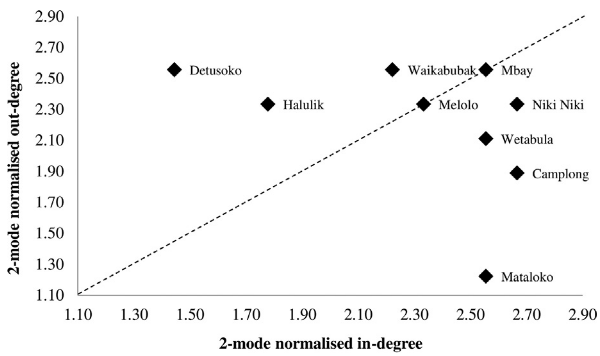

Fig. 3. 2-Mode normalised in and out-degree values for formal pig movements between villages and live pig markets across Nusa Tenggara Timur province, eastern Indonesia, 2009 (45° dashed line; 2-mode normalised degree calculation based on market network; Spearman rank: $r_{SP} = 0.948$, $P < 0.001$, $n = 9$).

Table 1
Social network analysis calculated parameters for formal movements (village-to-market network) for pig movements across Nusa Tenggara Timur province, eastern Indonesia, 2009, 2-mode (2m) normalised degree calculations based on island networks for West Timor Flores and Sumba with overall market network based on entire network across 2 market days.

Parameter	West Timor	Flores	Sumba	Overall market
Network size				
Number of villages nodes[a]	108	98	91	298
Number of markets nodes[a]	3	5	5	9
Number of directed links[b]	123	116	127	366
Size[c]	648	600	558	5364
Diameter[d]	6	4	4	8
Measures of centrality				
Mean in-degree (range)[e]	1.11 (0–24)	1.13 (0–23)	1.32 (0–23)	1.92 (0–24)
Mean out-degree (range)[f]	1.11 (0–21)	1.13 (0–23)	1.32 (0–23)	1.92 (0–23)
2m Normalised in-degree (range)[g]	0.37 (0–8.0)	0.23 (0–4.6)	0.26 (0–4.6)	0.21 (0–2.7)
2m Normalised out-degree (range)[h]	0.37 (0–7.0)	0.23 (0–4.6)	0.26 (0–4.6)	0.21 (0–2.6)
In-degree centralisation[i]	21.00	21.66	23.06	7.48
Out-degree centralisation[j]	18.25	21.66	23.06	7.15
Measures of cohesion				
2m Density[k]	0.19	0.19	0.23	0.07
Average geodesic distance (mode)[l]	3(2)	2(2)	2(2)	3(2)
Pig volumes				
Mean entering volume (range)	2.15 (1–95)	1.49 (1–84)	2.40 (1–140)	2.06 (1–140)
Mean exiting volume (range)	2.05 (1–81)	1.22 (1–24)	3.56 (1–166)	2.18 (1–166)

[a] Number of nodes: the total number of network members.
[b] Number of directed links: the total number of connections made between nodes.
[c] Size: the total number of possible unique node pairs.
[d] Diameter: the number of links in the largest possible pathway between two nodes.
[e] Mean in-degree: the count of contacts a node receives (movements to a location).
[f] Average out-degree: the number of contacts from a node (movements from a location).
[g] Normalised in-degree: the number of contacts to a node divided by the maximum number of possible contacts (2-mode normalised in-degree is calculated by in-degree divided by number of markets in network, Borgatti and Everett, 1997).
[h] Normalised out-degree: the number of contacts from a node divided by the maximum number of possible contacts (2-mode normalised out-degree is calculated by out-degree divided by number of markets in network, Borgatti and Everett, 1997).
[i] In-degree centralisation: An estimate of the deviation of the largest values of in-degree from the value computed for all other nodes in the network.
[j] Out-degree centralisation: An estimate of the deviation of the largest values of out-degree from the value computed for all other nodes in the network.
[k] 2m Density: The proportion of all contacts that could be present that actually are (2-mode is calculated by no. directed links divided by network size, Borgatti and Everett, 1997).
[l] Average geodesic distance: The shortest path length between two nodes.

3.2. *Informal network – village to village movements*

For informal movements between villages, there was much more fragmentation across the network with more localised movement (Figs. 5 and 6). On Sumba, Rindi and Kayuri villages (located within *Kab.* Sumba Timur) reported trading only with villages within that district. In the western region of the island, Rada Mata was the only village connecting the districts of Sumba Barat and Sumba Barat Daya. Similarly, in Flores a separation in the network can be observed between the eastern and western regions. For the eastern region of the island, Pruda was the only village connecting the districts Flores Timur and Sikka. The western region of the island was very segregated and had no reported connection to adjacent districts on the eastern end of the island. Minimal between-island movement was detected. West Timor displayed different visual network characteristics with all interview locations having some connectivity, with movement events entering all five districts (Figs. 5 and 6). Nunbaun Delha village in West Timor

Table 2
Market rankings according to in- and out-degree and volume of pigs entering and exiting a market node across West Timor, Flores and Sumba, Nusa Tenggara Timur Province, eastern Indonesia, 2009.

Island	Market	Out-degree	In-degree	2-Mode normalised out-degree	2-Mode normalised in-degree	Pig volume[a] out	Pig volume in
Flores	Detusoko	23	13	2.56	1.44	23	26
Sumba	Waikabubak	23	20	2.56	2.22	99	82
Flores	Mbay	23	23	2.56	2.56	24	29
Sumba	Melolo	21	21	2.33	2.33	84	87
West Timor	Niki Niki	21	24	2.33	2.67	47	59
West Timor	Halulik	21	16	2.33	1.78	40	64
Sumba	Wetabula	19	23	2.11	2.56	166	140
West Timor	Camplong	17	24	1.89	2.67	81	95
Flores	Mataloko	11	23	1.22	2.56	12	84

[a] Pig volume refers to the total number of pigs recorded at a market across the two interview periods in September and November.

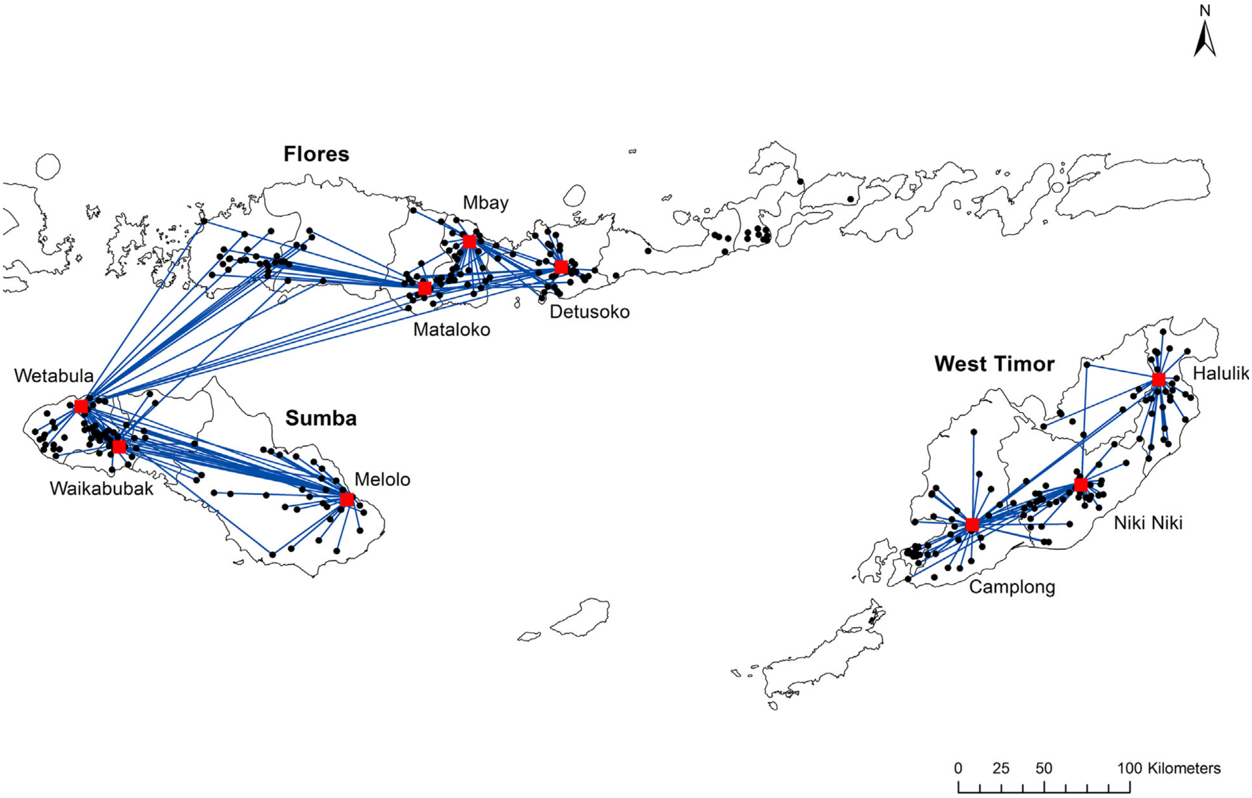

Fig. 4. Formal pig movements through nine major pig markets across Nusa Tenggara Timur province, eastern Indoneisa, 2009. Location reports from pig sellers and pig buyers during interviews at market sites; black circles: villages, red squares: live pig markets, blue lines: pig movement pathways; text: market names. (For interpretation of references to color in figure legend, refer to online version of article).

had the largest number of village contacts detected within the informal network (in-degree = 13).

The farmer network was made up of a total of 95 nodes, with Sumba having the largest network size (Table 3). Flores was found to have the smallest network size, which corresponded to a network diameter of only 4. A 2-node difference was detected between other island networks with a diameter of 6 estimated for West Timor and Sumba. A greater level of fragmentation was identified on Flores compared to Sumba and West Timor. A positive correlation was detected when comparing in- and out-degree values within the informal network (Spearman rank: $r_{SP} = 0.976$; $P < 0.001$, $n = 95$). For Flores, the average geodesic distance was found to be 1. This supported a greater level of localised movement with pigs often only moving from one village to another, commonly a neighbouring village within the same subdistrict. Pig volumes varied between islands, with Sumba having the greatest overall range. Rindi village was found to have the highest exiting pig volume (78 pigs during 2009–2010) and Kayuri village the greatest entering volume of pigs (61 pigs during 2009–2010).

For Flores there was the presence of two network components, one of size 17 and one of size 9. The larger component was weak with only one village connecting to an additional subdistrict and, being uni-directional, this limits its level of connectivity within the network (Fig. 5).

3.3. *Province network*

The overall province network combining both formal and informal movement events was made up of 369 nodes (Table 4). West Timor was found to have the greatest overall size and the greatest number of nodes. Sumba had the smallest size overall; however, it had the highest number of directed links identifying a pattern of high connectivity within the network. No overall increase in diameter was achieved by combining the market and farmer networks, with the maximum diameter remaining at 8. There was also no change to the average geodesic distance, remaining at 3 for the province level. This suggests that although the diameter reached 8, the majority of trade movements occur across a 2–3 node pathway. However for Sumba, combining the market and farmer networks did increase the geodesic distance, to mode value of 4, notably higher than the other islands. A positive correlation was detected between in- and out-degree values (Spearman rank: $r_{SP} = 0.975$; $P < 0.001$, $n = 369$). On average a village-to-market movement involved the transportation of five animals per market day whereas a farm-to-farm movement event involved an average of seven pigs per year. A mean of 2 ± 1.53 pigs was calculated (range: 1–20; $n = 153$) for single movement events for farmers during that year. The volume of pigs moving through the province network tended to be higher at the market level.

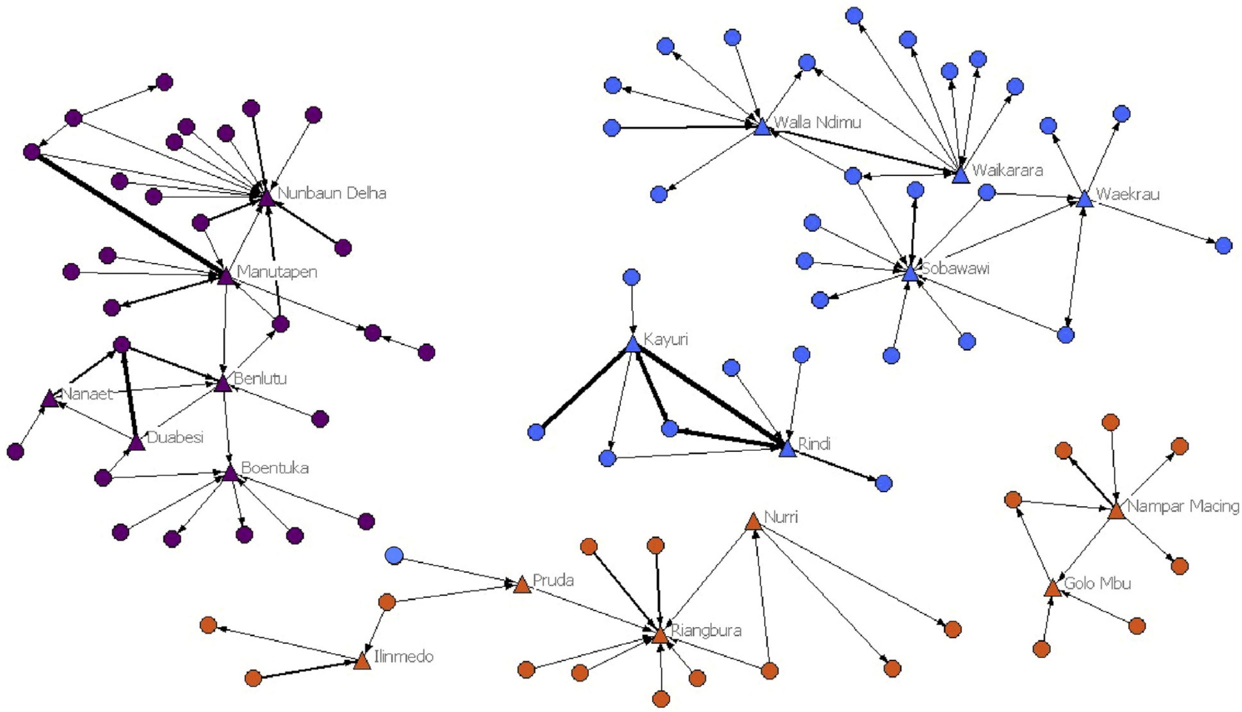

Fig. 5. Farmer network for informal pig movements across West Timor, Flores and Sumba, eastern Indonesia, 2009–2010 (Purple: West Timor; Blue: Flores; Orange: Sumba; Triangles: Village where interviews conducted; Circles: Villages connecting interview locations; Line thickness represents the volume of pigs moving between two nodes). (For interpretation of references to color in figure legend, refer to online version of article).

Regarding between-island movements, there were 14 villages connecting Flores and Sumba. The majority of these villages were located in the western districts of Flores. Only 1.8% (17/944) of movement events recorded were between islands with all but one event being formal uni-directional movements from Flores to Sumba, and the exception being one informal movement from Sumba to Flores) (Fig. 6 and Table 5). Regarding movement direction across Flores, it should be noted that all pigs were moved from west to east; there were no reports of pigs moving in the opposite direction. Sumba had the highest level of between-district movement, which is predominantly seen within the market network (Table 5). West Timor had the highest level of between-subdistrict movement when analysing the entire province network. However, it should be noted that for informal movements, West Timor had the highest level of between-district movement. Furthermore, Flores was estimated to have the highest level of within-subdistrict movement, from village-to-village. Overall, markets had a greater level of connectivity within the network with regards to in- and out-degrees. The nine market locations had higher normalised degree values with more localised movement associated with the informal network.

4. Discussion

Pig movements were identified both across and between islands within Nusa Tenggara Timor province. The extent and complexity of the network was greater than expected given previous work in this province: some pigs were known previously to be transported to Sumba and across the border into Timor Leste, most pig trade was considered local, i.e. within and between villages (Patrick et al., 1999; Johns et al., 2009). This study shows that smallholders trade pigs through markets as well as trade and gift pigs directly between villages, with over 60% of these transactions moving pigs beyond the subdistrict of origin. This makes pig raising a convenient and fast monetary source that ensures high demand during cultural events can be fulfilled.

Notable features of this smallholder pig network are the distances that pigs are transported – >25% of movements are between districts – and transport by ferry facilitating movement between islands for formal and for informal trade. It demonstrates that informal movement can involve transportation of pigs over similar distances to formal movement, and both formal and informal networks connect all five districts on West Timor from the district bordering East Timor to the western districts that include the provincial capital of Kupang. This emphasises the role of cultural practice and its influence on pig movement beyond what has been reported to date in the literature. The requirement of live pigs for slaughter is a predominant reason for consumer demand in this province that leads to a price differential between islands and results in pigs being moved considerable distances to be given as gifts at weddings, funerals and traditional ceremonies. Further, for villages and markets with high in-degree values, a characteristic found to be correlated with high out-degree values for each of the three networks in this study, the connections of these villages or markets with higher numbers of source villages and of destination villages make these sites

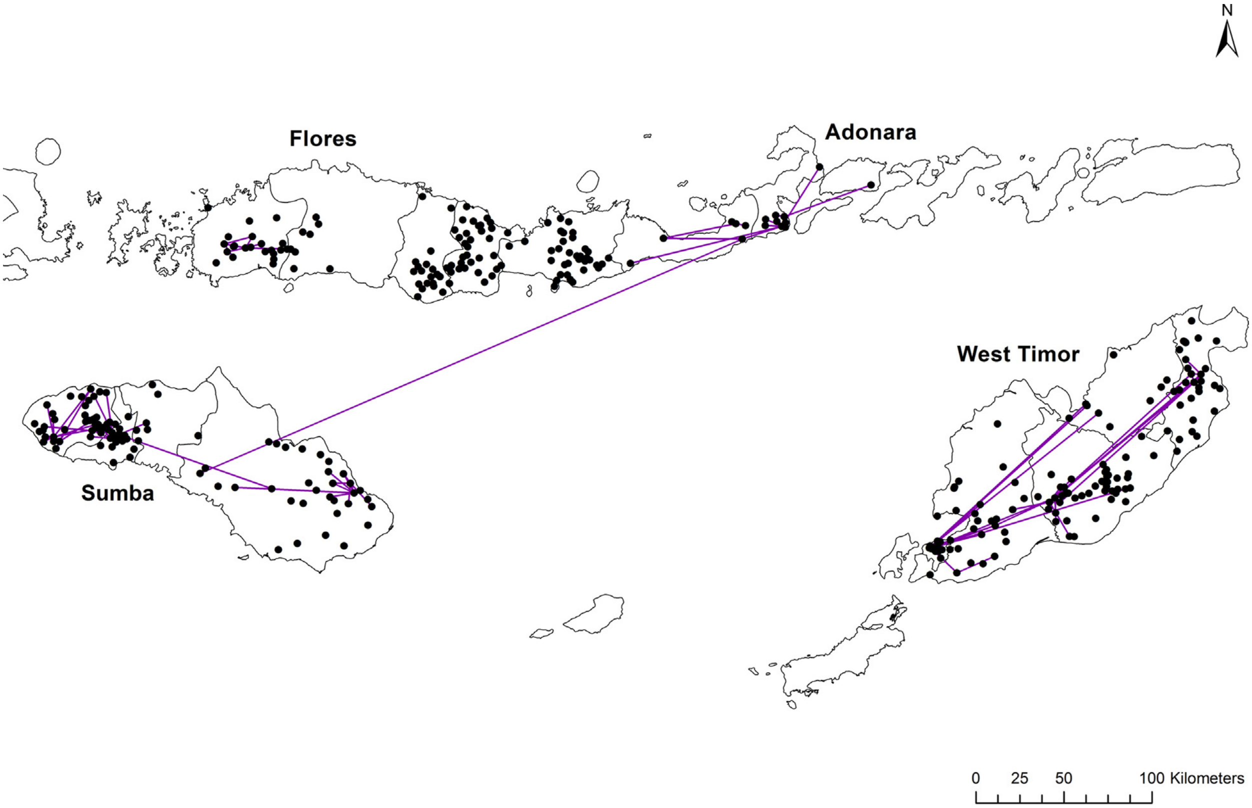

Fig. 6. Informal movements of pigs from village to village across Nusa Tenggara Timur province, eastern Indonesia 2009–2010; Black circles: Village locations reported by pig sellers, buyer and farmers. Nodes that are connected represent the informal pathways, those villages not connected to the network, represent those villages involved in formal movement through markets.

high risk for disease dispersal and thus key locations for education on CSF and biosecurity to instigate community awareness and involvement in preventing disease spread.

This network analysis included the movement of live pigs only because movement of pig products in NTT was known to be limited as evidenced by only 3.1% of the buyers reporting ever having purchased pig meat at markets (Leslie, 2012). All live pig movements, including pigs traded for slaughter, were retained in this network as animals destined for backyard slaughter may mix with other pigs prior to slaughter and for onward transmission via swill feeding post slaughter (Edwards, 2000; Fritzemeier et al., 2000; Kira and Kasman, 2011). This contrasts with commercial production systems in which movements of animals to slaughter may be considered end points for disease transmission and thus not be included in network analysis focused on disease pathways (Noremark et al., 2011).

As no pig movement recording scheme currently exists in NTT, a common feature of smallholder livestock systems, this network analysis was based on data obtained through interviews. This method of obtaining movement data has been used previously in similar contexts such as by Martin et al. (2011) to investigate the contact structure of the poultry market chain in South China and by Kerr et al. (2012) to investigate the trade network for cattle and buffalo in Cambodia and Laos. The conduct of interviews required market and village selection. Thus the results do not reflect entire networks, and reported network parameters such as geodesic distance, diameter, size and density calculations are biased towards their minimum values. Further, the sampling approaches used for the market and farmer surveys (Leslie, 2012) prevented the calculation of some SNA parameters, including betweeness, closeness, clustering coefficient, reachability and small world network analysis. The timescale for the interview data also needs to be considered with data obtained for the market network representing trade on two market days (one at a high-demand period and the other a low-demand period) and for the farmer network representing trade over one year by smallholder farmers. The purpose of combining the two networks was to create an overall province network which, although it is incomplete, did demonstrate the extent of pig movements occurring across the province and provide values that are informative because this network structure has not been studied before. Purposive selection of important markets selling large numbers of pigs and of districts with large pig populations and designated CSF status was a deliberate strategy to include study locations spanning the main islands and to capture movements from one end of the province to the other, if these existed. Contact locations presented in the analysis may not be representative of the region due to the sampling techniques used; these locations had a greater tendency to be located close to each

Table 3
Social network analysis calculated parameters for informal movements (village-to-village network) for pig movements across Nusa Tenggara Timur Province in eastern Indonesia, representing one year of pigs entering and exiting a village 2009–2010.

Parameter	West Timor	Flores	Sumba	Overall farmer
Network size				
Number of village nodes[a]	33	26	36	95
Number of directed links[b]	51	44	64	135
Size[c]	1056	650	1260	9120
Diameter[d]	6	4	6	6
Measures of centrality				
Mean in-degree (range)[e]	1.55 (0–13)	1.69 (0–11)	1.78 (0–11)	1.42 (0–13)
Mean out-degree (range)[f]	1.55 (0–7)	1.69 (0–7)	1.78 (0–11)	1.42 (0–9)
Normalised in-degree (range)[g]	2.34 (0–19.7)	2.17 (0–14.10)	2.47 (0–15.28)	0.75 (0–6.84)
Normalised out-degree (range)[h]	2.34 (0–10.6)	2.17 (0–8.97)	2.47 (0–15.28)	0.75 (0–4.74)
In-degree centralisation[i]	18.46	12.91	13.55	6.23
Out-degree centralisation[j]	8.79	7.36	13.55	4.07
Measures of cohesion				
Density[k]	0.043	0.045	0.041	0.013
Average geodesic distance (mode)[l]	2(2)	1(1)	3(2)	2(2)
Pig volumes				
Mean entering volume (range)	4.57 (1–33)	10.17 (1–39)	9.47 (1–56)	7.29 (1–56)
Mean exiting volume (range)	8.71 (1–39)	8.50 (1–48)	8.64 (1–78)	8.12 (1–78)

[a] Number of nodes: the total number of network members.
[b] Number of directed links: the total number of connections made between nodes.
[c] Size: The total number of possible unique node pairs.
[d] Diameter: the number of links in the largest possible pathway between two nodes.
[e] Mean in-degree: the count of contacts a node receives (movements to a location).
[f] Average out-degree: the number of contacts from a node (movements from a location).
[g] Normalised in-degree: the number of contacts to a node divided by the maximum number of possible contacts (2-mode normalised in-degree is calculated by in-degree divided by number of markets in network, Borgatti and Everett, 1997).
[h] Normalised out-degree: the number of contacts from a node divided by the maximum number of possible contacts (2-mode normalised out-degree is calculated by out-degree divided by number of markets in network, Borgatti and Everett, 1997).
[i] In-degree centralisation: an estimate of the deviation of the largest values of in-degree from the value computed for all other nodes in the network.
[j] Out-degree centralisation: an estimate of the deviation of the largest values of out-degree from the value computed for all other nodes in the network.
[k] 2m Density: the proportion of all contacts that could be present that actually are (2-mode is calculated by no. directed links divided by network size, Borgatti and Everett, 1997).
[l] Average geodesic distance: the shortest path length between two nodes.

other, particularly for the informal network. For the informal network, of the farmers interviewed only 62.3% had pigs enter and/or exit their herd during the preceding 12 month period; the remaining farmers therefore did not contribute data to the network. This possibly represents some selection bias that may mean these results have the potential to overestimate the number of village contacts for some villages included in the network, but the lack of reported movements of a substantial proportion of farmers is important to know for disease control programmes.

4.1. Formal market networks

The markets in this network, as known major trade points for pigs, act as a driving force for pig movement in NTT and this role is associated with proximity to consumer demand and thus sale price. Their influence is evident from sellers who transport pigs from western districts of Flores (where no pig markets exist) to central Flores and from Flores to Sumba by ferry in order to obtain higher return on pig sales (Kira and Kasman, 2011). This is similar to the Greater Mekong Sub-region where financial incentives drive the transport of livestock by traders from low-to-high price areas (Cocks et al., 2009). Although, across the NTT pig market chain, traders are less dominant and farmers are more likely to take their pigs directly to market (Leslie, 2012).

By identifying inter-island movement on ferries, this study highlights the need to consider ferry terminals and boats as locations for co-mingling of pigs and disease transmission. Ferry transportation in the province can take several hours, with trip length and frequency influenced by destination and season. For Indonesia, as an archipelago, ferry movement is an important method for product movement and its potential role in disease spread was investigated by De Glanville et al. (2009) who considered density of ferry ports as a risk factor for highly pathogenic avian influenza spread in this country. Whilst this analysis identified movements by ferry between Flores and Sumba, the ferry routes that operate on at least a weekly basis between West Timor, Flores and other islands in the province also need to be considered in terms of risk for disease spread – as does pig transport on smaller boats that are not registered ferries but are known to operate, although the extent of their movement is not currently known (Leslie, 2012).

4.2. Informal farmer networks

Lindström et al. (2009) demonstrated that between holding contacts (farm-to-farm) are more common across short distances. Although the study by Lindström et al. (2009) used cattle and pig movement data from Sweden, this same pattern was found across the informal networks in the current study. An increase in localised village movement and a reduction in between-district movement were identified. By trading in localised areas,

Table 4
Province social network analysis results for informal and formal pig movements across Nusa Tenggara Timur province, eastern Indonesia, 2009–2010.

Parameter	West Timor	Flores	Sumba	Overall Province
Network size				
Number of village nodes[a]	130	123	106	360
Number of market nodes[a]	3	5	5	9
Number of directed links[b]	165	143	167	501
Size[c]	17,556	16,256	12,210	135,792
Diameter[d]	8	6	6	8
Measures of centrality				
Mean in-degree (range) [e]	1.24 (0–24)	1.12 (0–23)	1.51 (0–23)	1.36 (0–24)
Mean out-degree (range) [f]	1.24 (0–21)	1.12 (0–23)	1.51 (0–23)	1.36 (0–23)
Normalised in-degree (range)[g]	0.93 (0–18.18)	0.87 (0–18.11)	0.68 (0–19.01)	0.18 (0–6.52)
Normalised out-degree (range)[h]	0.93 (0–15.91)	0.87 (0–18.11)	0.68 (0–19.01)	0.18 (0–6.25)
In-degree centralisation[i]	17.38	17.37	8.94	3.09
Out-degree centralisation[j]	15.09	17.37	8.94	2.95
Measures of cohesion				
Density[k]	0.0092	0.0110	0.0139	0.0036
Average geodesic distance (mode)[l]	3(2)	2(2)	3(4)	3(2)

[a] Number of nodes: the total number of network members.
[b] Number of directed links: the total number of connections made between nodes.
[c] Size: the total number of possible unique node pairs.
[d] Diameter: the number of links in the largest possible pathway between two nodes.
[e] Mean in-degree: the count of contacts a node receives (movements to a location).
[f] Average out-degree: the number of contacts from a node (movements from a location).
[g] Normalised in-degree: the number of contacts to a node divided by the maximum number of possible contacts (2-mode normalised in-degree is calculated by in-degree divided by number of markets in network, Borgatti and Everett, 1997).
[h] Normalised out-degree: the number of contacts from a node divided by the maximum number of possible contacts (2-mode normalised out-degree is calculated by out-degree divided by number of markets in network, Borgatti and Everett, 1997).
[i] In-degree centralisation: an estimate of the deviation of the largest values of in-degree from the value computed for all other nodes in the network.
[j] Out-degree centralisation: an estimate of the deviation of the largest values of out-degree from the value computed for all other nodes in the network.
[k] 2m Density: the proportion of all contacts that could be present that actually are (2-mode is calculated by no. directed links divided by network size, Borgatti and Everett, 1997).
[l] Average geodesic distance: the shortest path length between two nodes.

transportation issues such as distance and poor road infrastructure may be overcome, and seasonal influences will have a minimal impact on trade patterns (World Bank, 2006; Patunru et al., 2010). The influence of geography on a network can be surmised from the more fragmented informal network for Flores, an island that is mountainous with only one road linking east and west ends of the island and numerous isolated villages with minimal road access, compared to West Timor and Sumba that had informal movements between all districts on each island. In particular, informal movements in West Timor had a much higher level of connectivity compared to Flores and Sumba. This demonstrated that formal and informal pig movement pathways were similar distances in West Timor, incorporating between-district movements. This means informal movement can contribute to long distance disease spread in a similar manner to formal trade. For others working in smallholder livestock contexts, this finding indicates that both formal and informal movement should be investigated to inform disease control planning.

4.3. Considerations for CSF control

In view of the high level of connectivity found by this study, the control strategy for CSF must be formulated at the provincial level, and for Timor island in collaboration with East Timor, due to cross-border movement that can bring infected pigs into the well-connected flow of pigs for formal and informal trade across all districts of West Timor. Although the interviews that provided pig movement data for this study did not capture movement from East Timor to a village or market in West Timor, occurrence of such movements due to family connections among people of border districts and better sale prices at markets in West Timor is documented (Patrick et al., 1999; Abdurrahman, 2011) and further investigation to quantify the frequency and volume of such movements is warranted.

Currently CSF control in NTT involves a prohibition on pig movement from infected to non-infected districts and annual vaccination campaigns aim to reach over 50% of pigs in specific sub-districts identified on the basis of higher

Table 5
Province movement data: number and proportion of movement types stratified by island, district, subdistrict and within subdistrict movement including both formal and informal movement across West Timor, Flores and Sumba, Nusa Tenggara Timur Province, Eastern Indonesia, 2009–2010.

Province of origin	West Timor	Flores	Sumba	Total	%
Between island	0	16	1	17	1.80
Between district	63	61	134	258	27.33
Between subdistrict	138	99	122	359	38.03
Within subdistrict	77	127	106	310	32.84
Total	278	303	363	944	100.00

numbers of reported clinical cases of CSF. In addition, current legislation requires certificates for formal permitted movements between districts and islands (that is, movements for sale at markets between districts/islands of same CSF status or districts/islands of free status to infected status). This acts as a financial disincentive to pig trade and thus to some extent helps to reduce disease spread from districts with higher CSF levels. For example, inter-island trade requires the seller to obtain health and quarantine certificates from the District Livestock Services for a fee in addition to paying for ferry transport and then market entry tax on arrival at the destination market.

However these strategies are failing to be effective as illustrated by continuing reports of cases in Sumba and West Timor each year and by the outbreak in April 2011 on Lembata Island, previously a CSF-free district, following informal movement of infected pigs from Kupang West Timor to Lembata in violation of the movement regulation (Diarmita, 2012; Dinas Peternakan Propinsi, 2012).

The inadequacy of present control strategies and the findings of this study demonstrate that pig movement regulations on their own will not contain CSF, and suggest that introduction of systematic implementation of biosecurity and vaccination at the village level in sub-districts with higher CSF occurrence will over time reduce prevalence and thus reduce risk of CSF transmission with pig movements. The outcome of a programme on Alor Island (a single small island district in northern NTT) focused on improving pig nutrition using local feedstuffs and farmer knowledge of CSF, and on high sustained CSF vaccination coverage is promising in this regard with reported cases of CSF reduced from 106 in 2005 to zero from 2008 to 2014 (Robertson et al., 2010). To aid strategic planning further research on CSF prevalence in NTT and in East Timor is indicated as is consultation between the animal health authorities in Indonesia and East Timor to formulate an island-wide approach. It is recognised by these authorities that over the last decade the non-existent to minimal animal health services in border districts of East Timor has impeded CSF control efforts in West Timor.

5. Conclusion

This study has illustrated the extent of formal and informal pig movement in NTT province and characterised the features of key villages and markets that pose higher risk for infectious disease spread. It has shown that informal pig movement between smallholder farmers for the purposes of income generation and cultural practice is not always localised and in some instances can cover distances equivalent to formal movements. These findings have implications for disease control planning and demonstrate the value of knowledge about animal movement to underpin effective strategic approaches to the control of trans-boundary animal diseases. For NTT province with limited resources available for animal health and ongoing negative impacts of CSF, it suggests that CSF control should be formulated at the provincial level, and for Timor Island requires agreement and collaboration with East Timor. Further research on CSF prevalence in NTT and East Timor should be undertaken to delineate the areas with high prevalence that are the main contributors to pig movement such that these can be targeted for implementation of extension and vaccination efforts and surveillance activities.

Acknowledgements

The authors would like to thank the interview teams and respondents for their involvement in the study, the Provincial Animal Health Department in Kupang for their collaboration, the Australian Centre for International Agricultural Research (Project number: AH/2006/156) for funding the project, the Pork CRC for providing a Postgraduate Scholarship and Travel Grant for the student involved and the University of Sydney International Visiting Research Fellowship Scheme for supporting Robert Christley. This paper represents part of a thesis submitted by the lead author for award of a PhD at The University of Sydney.

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