Preventive Veterinary Medicine 162 (2019) 110–116

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

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

Production diseases in smallholder pig systems in rural Lao PDR

Hannah R. Holt[a,*], Phouth Inthavong[b], Kate Blaszak[c], Chattouphone Keokamphe[b], Anousone Phongmany[b], Stuart D. Blacksell[d,e,f], Peter A. Durr[g], Kerryne Graham[g], John Allen[g], Blánaid Donnelly[h,i], Kim Newberry[g], Delia Grace[k], Silvia Alonso[h], Jeff Gilbert[k], Fred Unger[j]

[a] Pathobiology and Population Sciences, Royal Veterinary College, Hertfordshire, UK
[b] Department of Livestock and Fisheries, Ministry of Agriculture and Forestry, Vientiane, Lao People's Democratic Republic
[c] Consultant for CSIRO - Australian Animal Health Laboratory, Geelong, Victoria, Australia
[d] Centre for Tropical Medicine and Global Health, Nuffield Department of Medicine, University of Oxford, Churchill Hospital, Oxford, UK
[e] Mahidol-Oxford Tropical Medicine Research Unit, Faculty of Tropical Medicine, Mahidol University, Bangkok, Thailand
[f] Lao-Oxford-Mahosot Hospital-Wellcome Trust Research Unit (LOMWRU), Mahosot Hospital, Vientiane, Lao People's Democratic Republic
[g] CSIRO - Australian Animal Health Laboratory, Geelong, Victoria, Australia
[h] Animal and Human Health Program, International Livestock Research Institute, Addis Ababa, Ethiopia
[i] Community Veterinary Outreach, Ottawa, Canada
[j] Animal and Human Health Program, International Livestock Research Institute, Hanoi, Vietnam
[k] Animal and Human Health Program, International Livestock Research Institute, Nairobi, Kenya

A R T I C L E I N F O

Keywords:
Pigs
Lao People's Democratic Republic
Foot and mouth disease
Classical swine fever
Erysipelas
Porcine reproductive and respiratory syndrome

A B S T R A C T

Pigs in Lao People's Democratic Republic are important for income and food security, particularly in rural households. The majority of pigs are reared in smallholder systems, which may challenge the implementation of any disease control strategies. To investigate risk factors for pig production diseases in such farming systems in the country a serological survey was conducted during 2011. A total of 647 pigs were sampled, accounting for 294 households in Luang Prabang and 353 in Savannakhet province representing upland and lowland, respectively. The results demonstrated that pigs in Lao PDR had antibodies against erysipelas (45.2%), CSF (11.2%), PRRS (8.6%), FMD O (17.2%) and FMD Asia 1, (3.5%). Differences in the housing systems influenced disease risk, for example, penned pigs had reduced odds of FMD and CSF, compared to those in scavenger systems. Pigs owned by farms using a sanaam (a communal area where pigs are kept for some time of the year) had 3.93 (95% confidence interval (CI): 1.09–14.7) times the odds of having pigs seropositive for FMD. Farms on which sudden piglet deaths had been experienced were more likely to have pigs seropositive for FMD O and erysipelas. These diseases constrain the development of village farming and the wider livestock industry due to their impact on productivity and trade. Vaccination coverage for FMD and CSF was low and there was a lack of national funding for livestock disease control at the time of the study. Further investigation into sustainable low-cost control strategies for these pathogens is warranted.

1. Introduction

Lao People's Democratic Republic (Lao PDR) is a landlocked country in Southeast Asia bordered by Vietnam, Cambodia, China, Myanmar and Thailand. Agriculture accounts for around 21.3% of the GDP and 73.1% of the labour force (CIA, 2017). Pigs are an important source of cash income and protein, particularly in rural areas. It is estimated that they are kept by approximately two-thirds of Laotian households, and are the most commonly owned livestock species after chickens (Wilson, 2007; Lao, 2012). In 2010/11, the pig population of Lao PDR was estimated at 0.98 million with pork being the most consumed meat in terms of individual meat consumption (kg/per person per year) (Agricultural Census Steering Comittee, 2012; FAOSTAT, 2013). Historically, most pig-owning households employed traditional farming practices (low-input, extensive scavenger systems). Around 80% of pigs are reared in smallholder systems with average number of pigs per household estimated at 3.2 with only 5% of households having ten or more pigs (Huynh et al., 2007).

Over the last 20 years enhanced infrastructure including the development of road networks and distribution channels has increased accessibility to remote villages in Lao PDR (Warr 2010). Although this has the advantages of linking farmers to markets and improving input

* Corresponding author.
E-mail address: hholt@rvc.ac.uk (H.R. Holt).

https://doi.org/10.1016/j.prevetmed.2018.11.012
Received 1 August 2018; Received in revised form 20 November 2018; Accepted 28 November 2018

access, increased animal and trader movement has also increased the risk of animal infectious disease transmission at the village level (Osbjer, 2006). Disease outbreaks have been reported as the most important constraint to pig production by village farmers (Phengsavanh et al., 2011). Pig farmers are transitioning to confined systems, at least for part of the year, in order to prevent cash-crop damage (Phengsavanh et al., 2011). It is thought that these changes to farming practices could reduce the risk of disease spread, however, evidence is limited (Phengsavanh et al., 2011).

Cross-border trade in livestock between the Southeast Asian countries have been linked to outbreaks of transboundary diseases such as Foot and Mouth disease (FMD) and Classical Swine Fever (CSF) (Perry et al., 2002). In addition, African Swine Fever (ASF) has recently been introduced into China and is an increasing threat to the South East Asia pig industry (Normile, 2018). Both CSF and FMD are already endemic in Lao PDR, and are characterised by periodical outbreaks. With up to 70% losses in village pig populations upon introduction, classical swine fever is one of the most important pig diseases in the country (Vongthilath and Blacksell, 2000; Conlan et al., 2011). Systematic surveillance of FMD in pigs in various regions in Lao PDR revealed seropositivity between 0 and 2.8%, whilst higher rates were observed through abattoir surveys (8.2%) with important geographical variations (Blacksell, Khounsy et al., 2008). Erysipelas, caused by *Erysipelothrix rhusiopathiae*, and porcine reproductive and respiratory syndrome are two other important pig production diseases with a worldwide distribution. Frequency of erysipelas occurrence among pigs in Lao PDR is currently unknown; a study conducted in Thailand found up to 15.0% of pigs at slaughter carrying the bacteria (Takahashi et al., 1999). PRRS is recognised as an economically important disease of pigs worldwide, causing reproductive failure in sows and respiratory disease in young pigs (OIE, 2008). Highly pathogenic – PRRS (HP-PRRS) emerged in China in 2006 and has since spread to the Southeast Asian region (Nguyen, 2013). It was confirmed for the first time in Lao PDR in June 2010; an estimated 3546 pigs died during the outbreak with an average mortality rate of 25% (Ni et al., 2012).

The aim of this study was to describe pig production and identify risk factors for endemic pig diseases in one northern upland (Luang Prabang) and one lowland southern (Savannakhet) province of Lao PDR. Such information is needed in inform locally adapted surveillance and control strategies for existing diseases and to contribute to the preparedness for incursions of new diseases such as ASF.

2. Methods

2.1. Study area

A cross-sectional study was conducted in 2011 in Luang Prabang and one lowland Savannakhet province of Lao PDR which differed in terms of climate, topography, farming systems, ethnicities and socio-economic status (Holt et al., 2016). Luang Prabang and Savannakhet provinces were selected for their location and to represent typical upland (and northern) and lowland (and southern) village systems and pig production. In addition, according to National statistics from 2009, these two provinces had the largest population of pigs. Luang Prabang province (20.21 °N, 102.62 °E), situated in northern Lao PDR covers an area of 16,875km^2 and shares a border with Vietnam. At an altitude of 700 to 1800 m above sea level. Savannakhet province (26.54 °N 105.78 °S) situated 145 m above sea level was selected as the lowland province with an area and population of 21,774 km^2 and 937,097, respectively. This province, situated in the southern-central part of the country shares a border with both Thailand (West) and Vietnam (East). The latest agricultural census, estimated that Savannakeht has 72,800 pigs (3.3 per km^2) and Luang Prabang has 113,100 (6.7 per km^2) (MAF, 2012; FAO, 2014). There is a large market in Luang Prabang that sources pigs from all districts and other provinces. In Savannakhet, there is an increasing number of commercial pig systems near the Thai border (Phengsavanh et al., 2011).

2.2. Selected diseases

Diseases were selected based on consultations with the National Animal Health Laboratories and on current evidence (Conlan et al., 2008a; Conlan et al., 2008b; Ni et al., 2012). Diseases were prioritised according to their impact on farm productivity (animal morbidity and mortality) and trade. Production diseases selected were; classical swine fever (CSF), erysipelas, foot and mouth disease (FMD) and porcine reproductive and respiratory syndrome (PRRS). The epidemiology of zoonotic diseases of porcine origin in the same settings (trichinellosis, cysticercosis, Japanese encephalitis and hepatitis E) has been reported elsewhere (Holt et al., 2016).

2.3. Study design

The study was a cross-sectional design conducted in parallel with a study investigating zoonotic diseases of porcine origin in pigs and humans in 2011. Protocols are described in detail in Holt et al. (2016). Briefly, 29 villages in Luang Prabang and 30 villages in Savannakhet were sampled probability proportional to human population as part of a parallel survey of pig zoonotic diseases in humans. Within villages, where possible up to 15 pig-owning households were randomly selected and one pig (over 12 weeks of age) was randomly selected in each household for blood sampling. A face-to-face pre-structured questionnaire was used to interview pig owners. The questionnaire collected pig health and management information. An additional questionnaire was conducted with the village head or village veterinary worker to gather relevant village-level information. As village selection was based on human population, villages were found to have a varying range of pig densities, and sampling 15 pig-owning households could not be achieved in all villages. In addition, not all villages had pigs available at the time of sampling.

2.4. Diagnostic testing

All laboratory testing was performed in Lao PDR at the National Animal Health Laboratory. Blood samples were collected using plain evacuated blood tubes and placed on ice until arrival at the laboratory where sera were separated and frozen at −20 °C for later analysis. Commercial kits were used for testing pig sera for *Erysipelas rhusiopathiae* antibodies using Cypress® SE/MR and PRRS antibodies (including HP-PRRS) using IDEXX® Herdcheck PRRSX3. Solid-phase cELISA' tests for FMD were developed by the Australian Animal Health Laboratories. Pig sera were tested for CSF antibodies using Prionics PrioCHECK® CSFV Ab2.0 which uses recombinant E2 antigens to detect CSF specific antibodies produced by vaccination or natural CSF infection, including subclinical infections. All questionnaire and serological data were entered into a custom-built web-based survey design and management application (*SurVet*). Inconclusive test results were classified as negative.

2.5. Statistical analysis

Descriptive statistics regarding pig management and percentage of pigs seropositive for each pathogen with 95% confidence intervals were calculated according to province. Seroprevalence estimates were not weighted according to pig population size in the village (these data were not available for many villages) therefore the results of this study refer to sample seroprevalence and do not represent population seroprevalence estimates. Univariate risk factor analysis was performed using chi-squared tests to explore association between selected independent variables and each outcome of interest (positive diagnostic test for a particular pathogen). Variables with $p \leq 0.2$ were included in multivariate logistic regression models. Village was included as a

Table 1
Village-level pig production characteristics in Luang Prabang and Savannakhet in 2011.

Production characteristic	Luang Prabang		Savannakhet	
	N (%)	95% CI	N (%)	95% CI
Purpose(s) of pig raising	***N = 22***		***N = 28***	
Sell piglets	6 (27.3)	11.6 to 50.4*	17 (60.7)	40.7 to 77.9*
Sell fattened pigs	19 (86.4)	64.0 to 96.4	17 (60.7)	40.7 to 77.9
Boar breeding	1 (4.5)	0.2 to 24.9	9 (32.1)	16.6 to 52.4
Village consumption	9 (40.9)	21.5 to 63.3	12 (42.9)	25.0 to 62.6
Movement[1]	***N = 22***		***N = 28***	
Pigs brought into village	10 (45.5)	25.1 to 67.3	17 (60.7)	40.7 to 77.9
Pigs slaughtered in village	15 (68.2)	45.1 to 85.3	21 (75.0)	54.8 to 88.6
Pigs sold outside village	21 (95.5)	75.1 to 99.8	24 (85.7)	66.4 to 95.3
Trader visits	20 (90.9)	69.4 to 98.4	26 (92.9)	75.0 to 98.8

* Significantly different between provinces – confidence intervals do not overlap.
[1] Whether at least one of the movements occurred in the last year for pig movements or the last month for trader visits.

random effect to control for assumed clustering of pigs within villages, a stepwise forward procedure was used and any variables associated with the outcome with $p \leq 0.05$ were retained in the model. For CSF, vaccinated pigs (as reported by owners) were excluded from the analysis. All statistical analyses were performed in R version 3.0.1.

3. Results

3.1. Descriptive statistics

A total of 647 pigs were sampled over the course of this study, accounting for a total of 294 pigs in 23 villages in Luang Prabang and 353 pigs in 28 villages in Savannakhet (some villages selected for human survey were not keeping pigs or in some villages the pigs were kept in a very distant sanaam area). Median herd sizes were 4 (inter-quartile range (IQR) = 2 to 6) in Luang Prabang and 2 (IQR = 1 to 4) in Savannakhet. Descriptions of relevant village-level variables collected from discussion with village head or village veterinary workers are presented in Table 1. The main purpose of pig raising in Savannakhet villages was reportedly to sell piglets and fattened pigs, whilst villages in Luang Prabang were more likely to sell just fattened pigs. In addition, most villages (except two in Luang Prabang and two in Savannakhet) reported pig traders visiting the villages. Villages in Luang Prabang tended to be closer to the district centre; with around one third of villages having less than 3 km to travel; compared to 11.0% in the Southern Province.

Household (HH) level variables regarding herd structure and management are presented in Table 2. Herd sizes appeared to be larger for most age groups for Luang Prabang and farmers here were more likely to call the village veterinary worker (VVW) when pigs were sick (91.1%). Less than 10% of pigs were moved to a sanaam at some point in the year (isolated area outside the village where pigs from different farms may mix). Approximately one quarter of new stock in both provinces comes from outside the villages and is of unknown health status. However, only 4.3% and 15.4% of farmers in Luang Prabang and Savannakhet systematically quarantined new animals, respectively. Around 40% of farmers in both provinces removed manure to use as fertilizer. In Luang Prabang, 40.9% of farmers let manure run off into water sources; whilst in Savannakhet 48.3% of farmers did not do anything with manure.

Most sampled pigs were local breeds or cross breeds and bred within the village (Table 3). The majority of exotic breeds were reportedly vaccinated against CSF (77.8%), whilst only 7.9% of local and cross-breed pigs were vaccinated. Almost all (> 85%) of pigs in Luang Prabang were kept in penned systems in both the wet and dry seasons.

Table 2
Pig management characteristics in study households (HH) sampled in Luang Prabang and Savannakhet in 2011.

Variable	Luang Prabang		Savannakhet	
	N (%)	95% CI	N (%)	95% CI
HH having sows	***N = 281***		***N = 353***	
Yes	162 (57.7)	51.6 - 63.5*	138 (39.1)	34.0 - 44.2*
HH having piglets	***N = 281***		***N = 353***	
Yes	60 (21.4)	16.8 - 26.7	78 (22.1)	18.0 - 26.9
HH having growers	***N = 281***		***N = 353***	
Yes	220 (78.3)	72.9 - 82.9	250 (70.8)	65.7 - 75.5
HH having boars	***N = 280***		***N = 353***	
Yes	40 (14.3)	10.5 - 19.1*	23 (6.8)	4.3 - 9.8*
Boar origin	***N = 280***		***N = 348***	
Always own hh or same village	201 (71.8)	66.1 -76.9*	167 (48.0)	42.6 - 53.4*
Another village (or both)	76 (27.1)	22.1 - 32.8*	46 (13.2)	9.9 - 17.3*
Not using boars	3 (1.1)	0.3 - 3.6*	135 (38.8)	33.7 - 44.2*
Sanaam access[1]	***N = 277***		***N = 353***	
Farm has access	16 (5.8)	3.4 - 9.4	27 (7.6)	5.2 - 11.1
Quarantine new pigs[2]	***N = 280***		***N = 352***	
Always	12 (4.3)	2.3 - 7.6*	55 (15.6)	12.1 - 19.9*
Never	247 (88.2)	83.7 - 91.6*c	244 (69.3)	64.2 - 74.0*
Sometimes	21 (7.5)	4.8 - 11.4	53 (15.1)	11.6 - 19.3
Uses of manure	***N = 279***		***N = 321***	
Remove for fertilizer	112 (40.1)	34.4 - 46.2	138 (43.0)	37.5 - 48.6
Leave in pen[3]	25 (9.0)	6.0 - 13.1	14 (4.0)	2.2 - 6.7
Run off into river/water supply	114 (40.9)	35.1 - 46.9	14 (4.0)	2.2 - 6.7
No use[4]	28 (10.0)	6.9 - 14.3	155 (48.3)	42.7 - 53.9
Action when pigs are sick (could select multiple)				
Call village veterinary worker	25 (8.9)	6.0 - 13.0*	103 (29.3)	24.6 - 34.4*
Farmer treats animals	120 (42.7)	36.9 - 48.7	114 (32.4)	27.6 - 37.6
Nothing	68 (24.2)	19.4 - 29.7*	32 (9.1)	6.4 - 12.7*
Herbal treatment	49 (17.4)	13.3 - 22.5*	1 (0.3)	0.0 - 1.8*
Sell pig	4 (1.1)	0.5 - 3.9	6 (1.7)	0.0 - 3.4
Kill/eat sick pigs	9 (3.2)	1.6 - 6.2	18 (5.1)	3.1 - 8.1
Pigs are never sick	9 (3.2)	1.6 - 6.2*	125 (35.5)	30.6 - 40.8*
Piglet deaths (past year)	***N = 281***		***N = 305***	
Yes	61 (21.7)	17.1 - 27.1	58 (19.0)	14.9 - 24.0
Adult pig deaths (past year)	***N = 281***		***N = 353***	
Yes	44 (15.7)	11.7 - 20.6	39 (11.0)	8.1 - 14.9
Vaccinations in the farm	***N = 280***		***N = 353***	
FMD	0	0.0 - 1.7	6 (1.7)	0.7 - 3.8
CSF	38 (13.6)	9.9 - 18.3	30 (8.5)	5.9 - 12.0

* Significantly different between provinces – confidence intervals do not overlap.
[1] A sanaam is a communal area where pigs are moved some times of the year.
[2] Quarantine was defined as keeping newly purchased pigs separate for at least 1 day.
[3] Combined with "other" for risk factor analysis.
[4] Generally do nothing: mostly because pigs are free-range/tethered and do not collect (74.3%) or it runs off into vegetable garden (6.0%).

Around two thirds of pigs in Savannakhet were kept penned or tethered, with a third being kept in extensive systems.

3.2. Serology results

Table 4 presents the number of samples positive to the selected pig pathogens. The percentage of pigs seropositive for PRRSV was similar in both provinces. Pigs in Luang Prabang were almost twice as likely to

Table 3
Study population characteristics of pigs sampled in Luang Prabang and Savannakhet in 2011.

Variable	Luang Prabang		Savannakhet	
	N (%)	95% CI	N (%)	% (95% CI)
Gender	***N = 288***		***N = 352***	
Male	62 (21.5)	17.0 to 26.7	70 (19.9)	15.9 to 24.5
Castrated male	53 (18.4)	14.2 to 23.5*	34 (9.7)	6.9 to 13.4*
Female	173 (60.1)	54.1 to 65.7	248 (70.5)	65.3 to 75.1
Age	***N = 187***		***N = 347***	
≤3 months	35 (18.7)	13.5 to 25.2	81 (23.0)	18.8 to 27.8
> 3 and ≤6 months	76 (40.6)	33.6 to 48.1	180 (51.1)	45.8 to 56.5
> 6 months	76 (40.6)	33.6 to 48.1*	86 (24.7)	20.4 to 29.6*
Housing (wet season)	***N = 288***		***N = 353***	
Penned	261 (90.6)	86.5 to 93.6*	153 (43.3)	38.1 to 48.7*
Tethered	0	0 to 1.6*	76 (21.5)	17.4 to 26.3*
Free-range some of the time	25 (8.7)	5.8 to 12.7	26 (7.4)	5.0 to 10.7
Free-range all the time	2 (0.7)	0.1 to 2.8*	98 (27.8)	23.2 to 32.8*
Housing (dry season)	***N = 288***		***N = 353***	
Penned	254 (88.2)	87.8 to 91.6	134 (38.0)	32.9 to 43.3*
Tethered	0	0 to 1.6*	96 (27.2)	22.7 to 32.2*
Free range some of the time	23 (8.0)	5.2 to 11.9	30 (8.5)	5.9 to 12.0
Free-range all the time	11 (3.8)	2.0 to 6.9*	93 (26.3)	21.9 to 31.3*
Contact with other pigs	***N = 283***		***N = 315***	
No contact with other pigs	33 (11.7)	8.3 to 16.1*	106 (33.7)	28.5 to 39.2*
Contact with 1 to 5 pigs	163 (57.6)	51.6 to 63.4	161 (51.1)	45.5 to 56.7
More than 5 pigs	87 (30.7)	25.5 to 36.5*	48 (15.2)	11.5 to 19.8*
Origin	***N = 284***		***N = 353***	
Bred by owner	127 (44.7)	38.9 to 50.7*	90 (25.5)	21.1 to 30.4*
Another farmer in village	88 (31.0)	25.7 to 36.8*	160 (45.3)	40.1 to 50.7*
Outside the village	69 (24.3)	19.5 to 29.8	103 (29.2)	24.5 to 34.3
Breed	***N = 288***		***N = 349***	
Local breed or crossbreed	288 (100)	98.4 to 100*	331 (94.8)	91.8 to 96.8*
Exotic breed	0	0 to 1.6*	18 (5.2)	3.2 to 8.2*
Pig vaccinated				
(could select multiple)	***N = 288***		***N = 353***	
FMD	0 (0)	0.0 to 1.7	6 (1.7)	0.7 to 3.8
CSF	38 (13.6)	9.9 to 18.3	30 (8.5)	5.9 to 12.0
Body Score[1]	***N = 281***		***N = 320***	
Less than 3	69 (24.6)	19.7 to 30.0*	120 (37.5)	32.2 to 43.1*
3	186 (66.2)	60.3 to 71.6*	140 (43.8)	38.3 to 49.4*
More than 3	26 (9.3)	6.2 to 13.4*	60 (18.8)	14.7 to 23.6*
Looks ill (observation)[1]	***N = 282***		***N = 353***	
Yes	19 (6.7)	4.2 to 10.5	11 (3.1)	1.6 to 5.7
Health problems (2 months)	***N = 277***			
(could select multiple)				
Coughing	20 (7.2)	4.6 to 11.1	12 (3.4)	1.9 to 6.1
Diarrhea	17 (6.1)	3.7 to 9.8*	1 (0.3)	0.0 to 1.8*
Lameness	7 (2.5)	1.1 to 5.4	2 (0.6)	0.0 to 2.3
Skin problems	10 (3.6)	1.8 to 6.7*	0	0.0 to 1.4*
Wasting	9 (3.2)	1.6 to 6.3	3 (0.9)	0.2 to 2.7

* Significantly different between provinces – confidence intervals do not overlap.
[1] The person sampling the pig was also recorded whether they pig looked unhealthy and their body score, with 3 = normal weight, 1 = emaciated and 5 = overweight: http://www.thepigsite.com/stockstds/23/body-condition-scoring/.

test seropositive for erysipelas (63.8% vs. 29.6%), whilst more pigs in Savannakhet were seropositive for CSF and all serotypes of FMD (Table 4). The most prevalent serotype for FMD appeared to be FMD O (17.4%), followed by A (8.8%). As many of the explanatory variables were highly correlated with province, province was not included in the multivariate models.

3.3. Risk factor analysis

Of the practices adopted by rural farmers in Lao PDR, housing appeared to play an important role, with penned pigs having 0.27 (95% confidence interval (CI): 0.10 to 0.70) and 0.28 (95% CI: 0.08 to 0.80) times the odds of FMD and CSF, compared to those in scavenger systems (Table 5). Further, pigs owned by farms that used a sanaam (an isolated, communal area where pigs from different owners are kept at some points in the year) were more likely to be seropositive for FMD. Manure management was an important factor for the risk of erysipelas with farms actively removing manure for fertilizer having the lowest risk. The only significant risk factor for PRRS was seropositivity for erysipelas.

4. Discussion

Diseases are reportedly a major limitation to the optimisation of pig production in Lao PDR (Okello et al., 2017). One of the first steps in controlling pig production diseases is to understand their distribution and farming practices at regional and national levels. This study provides data on village pig production and investigated the epidemiology of production pathogens in an upland (Luang Prabang) and lowland (Savannakhet) province of Lao PDR, where national funding for surveillance is lacking and there is a shortage of trained veterinarians (Vongthilath and Blacksell, 2000; FAO, 2014). At the time of the study, the majority of households kept on average three pigs and 20% reported sudden piglet deaths in the last 12 months. This is in agreement with recent data, indicating low-input systems with poor biosecurity, high mortality and low growth rates are still more common for village pig

Table 4
Comparison of number and percentage of positive samples of the selected pathogens in *Luang Prabang and Savannakhet in 2011*.

Pathogen	Luang Prabang		Savannakhet		Villages Pos % (95% CI)
	Pos (%)	95% CI	Pos (%)	95% CI	
CSF					
unvaccinated (N = 631)	12 (4.7)	2.6 to 8.3*	52 (16.2)	12.4 to 20.8*	40.4 (27.3 to 54.9)
vaccinated (N = 60)	7 (19.4)	8.8 to 36.6	9 (37.5)	19.6 to 59.2	44.2 (30.7 to 58.6)
Erysipelas					
unvaccinated (N = 637)	186 (68.3)	62.4 to 73.8*	102 (29.6)	24.9 to 34.7*	92.3 (80.6 to 97.5)
FMD any					
unvaccinated (N = 609)	17 (6.0)	3.6 to 9.6*	102 (31.5)	26.5 to 36.9*	44.2 (30.7 to 58.6)
vaccinated (N = 6)	NA	NA	0 (0.0)	NA	
FMD O					
unvaccinated (N = 609)	16 (5.6)	3.3 to 9.1*	90 (27.8)	23.0 to 33.1*	40.4 (27.3 to 54.9)
vaccinated (N = 6)	NA	NA	0 (0.0)	NA	
FMD A					
unvaccinated (N = 611)	3 (1.0)	0.3 to 3.2*	51 (16.0)	12.2 to 20.6*	34.6 (22.3 to 49.2)
vaccinated (N = 6)	NA	NA	0 (0.0)	NA	
FMD Asia 1					
unvaccinated (N = 615)	0 (0.0)	0 to 1.6*	22 (6.9)	4.4 to 10.3*	13.5 (6.0 to 26.4)
vaccinated (N = 5)	NA	NA	0 (0.0)	NA	
PRRS (N = 636)	27 (9.3)	6.3 to 13.3	28 (8.1)	5.6 to 11.7	51.9 (37.8 to 65.8)

* Significantly different between provinces – confidence intervals do not overlap.

Table 5
Risk factors for seropositivity for FMD O, erysipelas, CSF and PRRS for pigs in Luang Prabang and Savannakhet in 2011.

Variable	OR (95% CI)
FMD[1]	
Housing in dry season	
Free-range	Ref
Penned	0.27 (0.11 to 0.67)
Tethered	0.77 (0.28 to 2.12)
Using Sanaam	
No	Ref
Yes	3.34 (1.23 to 9.32)
Erysipelas	
Housing in dry season	
Penned	Ref
Free-range	0.90 (0.43 to 1.86)
Tethered	0.39 (0.14 to 1.01)
Manure	
Fertiliser	Ref 2.13 (1.20 to 3.83)
Other	1.49 (0.71 to 3.01)
Water sources	
Province	
North	Ref
South	0.12 (0.06 to 0.24)
Age (months)	1.06 (1.03 to 1.09)
CSF	
Housing in dry season	
Free-range	Ref
Penned	0.28 (0.08 to 0.80)
Tethered	0.30 (0.06 to 1.40)
Age (months)	1.06 (1.02 to 1.10)
PRRS	
Positive for erysipelas	
No	Ref
Yes	2.01 (1.36 to 2.68)

[1] Positive for any serotype.

rearing in Lao PDR (Burniston, 2016; Okello et al., 2017; Tiemann et al., 2017). In this study, the highest percentage of seropositivity was found for erysipelas (45.2%) and FMD (19.5%), followed by CSF (12.6%) and PRRS (8.7%). In another survey conducted in pigs in two bordering provinces of Luang Prabang, a similar seroprevalence estimate was obtained for PRRS, whilst only 1.6% (95% CI 0.4 to 5.5%) of pigs were seropositive for CSF (Okello et al., 2017). The majority of pigs seropositive for CSF in the current study were from Savannakhet province (16.2% vs. 4.8% in Luang Prabang), suggesting this may be more prevalent in Southern Lao PDR. Exposure to FMD also appeared higher in Savannakhet compared to Luang Prabang province, and this is in agreement with previous studies (Blacksell et al., 2008). Although these variables were not retained in the final models as they are outcomes of the disease rather than risk factors, farmers that had experienced sudden piglet deaths and adult pig deaths were more likely to have pigs seropositive for FMD and erysipelas, respectively. Indicating that these pathogens may be associated with production losses. Following its recent incursion into China, ASF poses an imminent threat to the South East Asian pig industry including Lao PDR. The disease is highly transmissible and causes haemorrhagic fever in pigs that is usually fatal and for which there is no effective treatment or available vaccine (Normile, 2018). Given the lack of village-level biosecurity, semi-free-range practices indicated by this study and the cross-border trade of pigs and pork-products this disease poses and imminent and potentially devastating threat to Laotian pig industry. Emergency meetings of representative South East Asian countries are being held for prevention and control planning, in addition the issue was discussed at regional laboratory meetings in Lao PDR (FAO, 2018). The data presented here on pig production systems and risky practices were collected in conjunction with the Ministry of Livestock and Fisheries and has been useful to inform preparedness to reduce the risk of introduction and spread within Lao PDR. It is recommended that pigs are reared in confined systems in order to reduce disease spread (Costard et al., 2009; Dione et al., 2014). Most farmers kept pigs penned or tethered, however, up to 11.8% of pigs in Luang Prabang were free-range at least some of the time, and this increased to a third in Savannakhet. Pigs raised in these scavenger systems had increased odds for both FMD and CSF, compared to those in confined systems. Once introduced into a system with intensive contact, poor hygiene and lack of preventive measures, infections can spread quickly and have an even higher impact (Tiemann et al., 2017). Pigs from farms which used a sanaam had 3.93 (1.09 to 14.7) times the odds of testing seropositive for FMD which was unexpected as sanaams were hypothesised to be a useful control option. Only around 7% of farmers were using sanaams which is relatively low and may mean that the apparent association is due to some other unmeasured characteristic in those few farms/villages. Around a quarter (27.5%) of villages had some farmers using a sanaam therefore, although not homogenously distributed across villages, it is not only clustered to a very small number of villages. Further the variable had a similar distribution between Luang Prabag and Savannakhet Provinces. Alternatively, although sanaams may seem like a useful control option pigs from different farms are kept in close confinement and systems that facilitate contact between animals from different herds are frequently associated with outbreaks of viral pig diseases (Megersa et al., 2009). Therefore, if a pathogen is introduced into the village, sanaams may facilitate within village spread especially if biosecurity e.g. cleaning between batches is low or, as was the case in some villages in the field survey, the sanaams are far away from the village their use promotes contact with pigs from other villages or wildlife. A previous study found that it was common for pigpens in Laotian villages to be next to streams to access water for consumption and cleaning (Okello et al., 2017). Around a third of respondents in Luang Prabang disposed of pig faeces in water supplies and this, and not removing manure from pig housing, had increased odds of testing seropositive for erysipelas. Waste from infected pigs may contain pathogens, which could represent a risk other pigs and, in the case of zoonotic pathogens, a public health risk (Dione et al., 2014; Holt et al., 2016).

One of the study limitations is that robust province level seroprevalence estimates were not possible due sampling probability proportional to human population and the lack of pig-population data. However, a large number of pigs were tested during the course of the survey and it was assumed that larger human populations would generally be associated with higher pig populations. Therefore, the sample seroprevalence should give an indication of the level of exposure to the different diseases in the study. Another limitation is that the data was collected several years ago in 2011 and the situation may have changed, however more recent data suggests production is still similar and the studied diseases are still endemic (Burniston, 2016; Okello et al., 2017; Tiemann et al., 2017). Due to the cross-sectional design, villages were visited at different times so do not take into account seasonality. However, the use of serological tests does mean that past infections are included in the study. Another limitation is the lack of records for the production and risk factor data collected; accuracy of these data depends on the recall of farmers however, the enumerators could crosscheck many of the variables collected during the fieldwork. As the diagnostic tests used for PRRS cannot distinguish between exposure to Highly Pathogenic (HP-PRRS) and low pathogenic PRRS strains, we cannot be sure to which virus type pigs were exposed.

Quarantine of new pigs and appropriate movement controls could be key for prevention and control of disease outbreaks, particularly CSF and FMD and if introduced, ASF in immunologically naïve pigs (Cleland et al., 1996). However, quarantine is not widely practiced and when practiced the median length of quarantine was 7 days. The pathogens in this study can have incubation periods longer than a week, therefore clinical signs may not be apparent until after this period. The majority of farmers managed pig diseases themselves in this study, with an estimated 2% of rural villages in Lao PDR have a veterinary clinic (Burniston, 2016). However, around 30% of respondents in Savannakhet and 8.9% in Luang Prabang reported calling a village veterinary worker (VVW) when their pigs were sick. VVW's are usually smallholders with limited training that assist with animal health concerns at the village level usually without any financial compensation (FAO, 2014). In low resource settings such as this, community animal health workers can bridge the gap between official veterinary systems and communities, playing an important role in disease control and official surveillance systems (Allport et al., 2005). Particularly in Savannakhet, VVW's could be useful in promoting good village- and pen-level biosecurity measures such as quarantine and use of confined systems. However, this may require additional support such as refresher training and mechanisms that allow them to recover costs of their services (Mravili et al., 2009). This is especially timely given that an outbreak of ASF has recently been reported in Southern China, not far from Northern Lao PDR border. As the study has demonstrated endemicity of CSF and PRRS, this may mean VVW's would not recognise or report ASF. Therefore, it is important for VVW's to be encouraged to report pig deaths and fever cases to field animal health staff. In addition to pig movement, 90% of villages in Savannakhet reported trader visits in the last month, compared to 69% in Luang Prabang. Middlemen may introduce disease if entering the villages with live animals, or via fomites (Osbjer, 2006). Further common management practices such as sharing of boars may further potentiate the spread of disease and some farmers may not be able to afford the costs associated with total confinement (Dione et al., 2014). Lao PDR is also a transit country for the Southeast Asia region and livestock movements into the country further impede disease control efforts (Kerr et al., 2012). Outbreaks of diseases such as FMD and HP-PRRS in Lao PDR have been attributed to livestock movements within the region, including Savannakhet (Perry et al., 2002; Ni et al., 2012). Checkpoints for livestock imports and exports exist in 25 locations in Lao PDR and all animals crossing are mandated to undergo inspection, but training of checkpoint staff may be limited and illegal trade is common (Osbjer, 2006). Given the high transmissibility of these diseases, vaccination may be a more appropriate control measure in villages with high between- and within-village livestock contract rates.

Vaccination coverage in the current study was low ($< 10\%$ for CSF and $< 2\%$ for FMD) which is in agreement with other reports (Burniston, 2016; Okello et al., 2017; Phengvilaysouk et al., 2017). Data from this, and other studies, can inform vaccination campaigns by identifying circulating virus serotypes and determining disease distribution. A lack of funds to pay for interventions for livestock diseases has been cited as a major constraint to pig production (Burniston, 2016). For diseases with high farm-level impact such as CSF, which had the highest vaccination coverage in the current study, the private benefits of vaccination are tangible and likely to be perceived as higher by farmers (providing the vaccine is efficacious) (Osbjer, 2006). Farmer willingness to use and pay for FMD vaccines, which has lower mortality and morbidity in pigs (Perry et al., 2002), may be less, and this may explain the lack of any vaccination coverage for FMD at the time of the study. As the presence of FMD and CSF can impact all pig farmers (and other livestock farmers in the case of FMD) linked geographically or via market chains, control of these pathogens creates positive externalities and may justify public funding. Lao PDR is a member of the South-East Asia Foot and Mouth Disease (SEAFMD) campaign that coordinates disease control within the region and a major FMD control initiative was launched in Northern Lao PDR in 2014; therefore vaccination coverage is now likely to be higher in the region (OIE, 2014). The programme aims to have zero outbreaks in 26 high-risk districts by 2016. However, the SEAFMD project appears to focus on cattle and data regarding the coverage of this control programme rural in areas and the impact on smallholder pig farmers is not currently available in the public domain. As almost 20% of rural pigs were exposed to at least one strain of FMD in the current study, exclusion of rural smallholders from vaccination campaigns may undermine control programmes for the disease.

5. Conclusion

Pigs in Lao PDR are exposed to CSF, erysipelas, PRRS and FMD, which constrain the development of the livestock industry due to their impact on productivity and trade. The majority of pig farmers were smallholders, although intensification is growing. The nature of these smallholder systems makes the implementation of disease control strategies challenging. Vaccination may be an effective option for disease control, particularly in areas with high within- and between- village contact rates. However, there is a lack of funding for livestock production and animal disease control including a shortage of Laotian veterinarians. Engaging with farmers through VVW's and promoting good biosecurity practices by increasing awareness of disease transmission and prevention may be a more sustainable. This is particularly important given the recent incursion of ASF into China which is currently threatening the South East Asian pig industry.

Funding

This research was jointly funded by the Australian Centre for International Agriculture Research (ACIAR) and the International Development Research Centre (IDRC: grant number 104266-001). Stuart D. Blacksell is funded by the Wellcome Trust of the Great Britain. The funders had no role in study design, data collection and analysis or preparation of the manuscript.

Ethical approval

Ethical approval was granted by the Institutional Research Ethics Committee (IREC) of the International Livestock Research Institute (ILRI) and the National Ethics Committee for Health Research in Lao PDR (No. 772 NIOPH/NECHR). Owners of selected pigs were asked to give informed consent to be interviewed and for their pigs to be sampled.

Competing interests

The authors confirm they have no competing interests.

Acknowledgements

This research was jointly funded by the Australian Centre for International Agriculture Research (ACIAR: grant numbers AH/2009/001 and AH/2010/019) and the International Development Research Centre (IDRC: grant number 104266-001). Stuart D. Blacksell is funded by the Wellcome Trust of the Great Britain. The funders had no role in study design, data collection and analysis or preparation of the manuscript.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2018.11.012.

References

Agricultural Census Steering Comittee, 2012. Lao census of agriculture 2010/11 highlights. Steering Committee for the Agricultural Census.

Allport, R., Mosha, R., Bahari, M., Swai, E., Catley, A., 2005. The use of community-based animal health workers to strengthen disease surveillance systems in Tanzania. Revue Scientifique et Technique-Office international des épizooties 24 (3), 921.

Blacksell, S., Khounsy, S., Conlan, J., Gleeson, L., Colling, A., Westbury, H., 2008. Foot and mouth disease in the Lao People's Democratic Republic: II. Seroprevalence estimates, using structured surveillance and surveys of abattoirs. Revue scientifique et technique 27 (3), 851.

Burniston, S., 2016. Mixed Methods Analysis of Pig Associated Zoonoses in Lao PDR. Doctor of Philosophy. The University of Edinburgh.

CIA, 2017. The World Factbook - Laos. Retrieved 19th Jan, 2017, from. https://www.cia.gov/library/publications/the-world-factbook/geos/la.html.

Cleland, P.C., Baldock, F.C., Chamnanpood, P., Gleeson, L.J., 1996. Village level risk factors for foot-and-mouth disease in Northern Thailand. Prev. Vet. Med. 26 (3), 253–261.

Conlan, J., Vitesnik, T., Khounsy, S., Wilks, C., Gleeson, L., 2008a. Classical Swine Fever Virus Vaccine Stability in Lao PDR.

Conlan, J.V., Blacksell, S.D., Morrissy, C.J., Colling, A., 2008b. Management of Classical Swine Fever and Foot-and-mouth Disease in Lao PDR. ACIAR.

Conlan, J.V., Jarman, R.G., Vongxay, K., Chinnawirotpisan, P., Melendrez, M.C., Fenwick, S., Thompson, R.C.A., Blacksell, S.D., 2011. Hepatitis e virus is prevalent in the pig population of Lao People's Democratic Republic and evidence exists for homogeneity with Chinese Genotype 4 human isolates. Infect. Genet. Evol. 11 (6), 1306–1311.

Costard, S., Wieland, B., De Glanville, W., Jori, F., Rowlands, R., Vosloo, W., Roger, F., Pfeiffer, D.U., Dixon, L.K., 2009. African swine fever: how can global spread be prevented? Philos. Trans. R. Soc. B: Biol. Sci. 364 (1530), 2683–2696.

Dione, M.M., Ouma, E.A., Roesel, K., Kungu, J., Lule, P., Pezo, D., 2014. Participatory assessment of animal health and husbandry practices in smallholder pig production systems in three high poverty districts in Uganda. Prev. Vet. Med. 117 (3-4), 565–576.

FAO, M., 2014. Lao Census of Agriculture 2010/11 Analysis of Selected Themes. from. http://www.fao.org/3/a-at767e.pdf.

FAO, 2018. UN FAO Convenes Emergency Meeting of Animal Health Experts in Asia in Response to African Swine Fever Threat. from Last accessed 20th Nov 2018. http://www.fao.org/asiapacific/news/detail-events/en/c/1151566/.

FAOSTAT, D., 2013. Food and Agriculture Organization of the United Nations. Statistical database. .

Holt, H.R., Inthavong, P., Khamlome, B., Blaszak, K., Keokamphe, C., Somoulay, V., Phongmany, A., Durr, P.A., Graham, K., Allen, J., Donnelly, B., Blacksell, S.D., Unger, F., Grace, D., Alonso, S., Gilbert, J., 2016. Endemicity of zoonotic diseases in pigs and humans in lowland and upland lao PDR: identification of socio-cultural risk factors. PLoS Negl. Trop. Dis. 10 (4), e0003913.

Huynh, T., Aarnink, A., Drucker, A., Verstegen, M., 2007. Pig production in Cambodia, Laos, Philippines, and Vietnam: a review. Asian J. Agric. Dev. 4 (1), 69–90.

Kerr, J., Hawkins, C., Davun, H., et al., 2012. Understanding livestock movement and the risk of spread of transboundary animal diseases. Final Report AH/2006/025 Canberra, Australia, Australian Centre for International Agricultural Research, Australian Government.

Lao, P., 2012. Lao census of agriculture 2010/11 highlights. Steering Committee for the Agricultural Census, Agricultural Census Office.

MAF, 2012. Lao Census of Agriculture 2010/11: Analysis of Selected Themes. Vientiane Ministry of Agriculture and Forestry. Agricultural Census Office.

Megersa, B., Beyene, B., Abunna, F., Regassa, A., Amenu, K., Rufael, T., 2009. Risk factors for foot and mouth disease seroprevalence in indigenous cattle in Southern Ethiopia: the effect of production system. Trop. Anim. Health Prod. 41 (6), 891–898.

Mravili, A., Banak, J., Chhetri, P., Baka, S., Kayanga, L., Awok, D., Antioko, M., 2009. Assessment Report - Community Based Animal Health Services. from. . http://www.fao.org/ag/againfo/resources/documents/AH/Sudan_Assessment_Report.pdf.

Nguyen, T., 2013. PRRS control in the region. Compendium of Technical Items of the 28th Conference of the OIE Regional Commission for Asia, the Far East and OceaniaWorld Organisation for Animal Health.

Ni, J., Yang, S., Bounlom, D., Yu, X., Zhou, Z., Song, J., Khamphouth, V., Vatthana, T., Tian, K., 2012. Emergence and pathogenicity of highly pathogenic Porcine reproductive and respiratory syndrome virus in Vientiane, Lao People's Democratic Republic. J. Vet. Diagn. Invest. 24 (2), 349–354.

Normile, D., 2018. Arrival of Deadly Pig Disease Could Spell Disaster for China. from Last accessed 20th Nov 2018. http://science.sciencemag.org/content/361/6404/741.

OIE, 2008. PRRS: The Disease, Its Diagnosis, Prevention and Control." Appendices IV and V of the Report of the Ad Hoc Group on Porcine Reproductive and Respiratory Syndrome Retrieved 19th Jan. 2017, from. . http://www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/PRRS_guide_web_bulletin.pdf.

OIE, 2014. The South-East Asia and China Foot and Mouth Disease (SEACFMD) Campaign. Retrieved 30th April 2018, from. http://www.rr-asia.oie.int/activities/sub-regional-programme/seacfmd/.

Okello, A.L., Tiemann, T.T., Inthavong, P., Khamlome, B., Phengvilaysouk, A., Keonouchanh, S., Keokhamphet, C., Somoulay, V., Blaszak, K., Blacksell, S.D., 2017. Integrating market chain assessments with zoonoses risk analysis in two cross-border pig value chains in Lao PDR. Asian-Australas. J. Anim. Sci. 30 (11), 1651.

Osbjer, K., 2006. Methodology in Recording Data on Pig Health and Production in the Lao People's Democratic Republic, Slu.Methodology in Recording Data on Pig Health and Production in the Lao People's Democratic Republic, Slu.

Perry, B., Gleeson, L., Khounsey, S., Bounma, P., Blacksell, S., 2002. The dynamics and impact of foot and mouth disease in smallholder farming systems in South-East Asia: a case study in Laos. Revue Scientifique et Technique (International Office of Epizootics) 21 (3), 663–673.

Phengsavanh, P., Ogle, B., Stür, W., Frankow-Lindberg, B.E., Lindberg, J.E., 2011. Smallholder pig rearing systems in northern Lao PDR. Asian-Australas. J. Anim. Sci. 24 (6), 867–874.

Phengvilaysouk, A., Jansson, A., Phengsavanh, P., Tiemann, T., Phengvichith, V., Lindberg, J.E., 2017. Sow and piglet management in small-holder and larger-scale pig farms in Northern part of Laos. Livestock Res. Rural Dev. 29 (10), 127.

Takahashi, T., Sunama, P., Satra, J., Cholsindhu, N., Skongthon, S., Jitnupong, W., Yamamoto, K., Kijima, M., Furuuchi, S., 1999. Serotyping and pathogenicity of Erysipelothrix strains isolated from tonsils of slaughter pigs in Thailand. J. Vet. Med. Sci. 61 (9), 1007–1011.

Tiemann, T.T., Phengvilaysouk, A., Keonouchanh, S., 2017. Herd dynamics reflect constraints for pig production and farmer attitudes in smallholder systems in Lao PDR. Anim. Prod. Sci.

Vongthilath, S., Blacksell, S., 2000. Classical swine fever in Lao PDR. ACIAR PROCEEDINGS, ACIAR; 1998.

Warr, P., 2010. Roads and poverty in rural laos: an econometric analysis. Pacific Econ. Rev. 15 (1), 152–169.

Wilson, R.T., 2007. Status and prospects for livestock production in the Lao People's Democratic Republic. Trop. Anim. Health Prod. 39 (6), 443–452.