

Implementing large Foot and Mouth Disease vaccination programmes for smallholder farmers: lessons from Lao PDR

Original Paper

Cite this article: Nampanya S, Khounsy S, Abila R, Windsor PA (2018). Implementing large Foot and Mouth Disease vaccination programmes for smallholder farmers: lessons from Lao PDR. *Epidemiology and Infection* **146**, 2086–2095. <https://doi.org/10.1017/S0950268818002443>

Received: 27 April 2018

Revised: 4 July 2018

Accepted: 30 July 2018

First published online: 23 August 2018

Key words:

Developing countries; Foot and Mouth Disease; large ruminant health; vaccination

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Abstract

This study assessed smallholder finances and their attitudes towards the Foot and Mouth Disease (FMD) vaccination programme, when 1 620 000 vaccine doses were provided for strategic administration in large ruminants in FMD ‘high-risk’ areas in Laos between 2012 and 2016. Farmers ($n = 168$) in the provinces of Xayabouli (XYL), Xiengkhoung (XK) and Huaphan (HP), were interviewed. Over 91% of the farmers responded that their livestock were vaccinated for FMD, with over 86% ranking FMD vaccination as a good or very good intervention. No FMD cases were reported from the vaccinated provinces after May 2013. Examination of the total income per household in XYL, XK and HP indicated earnings of US\$5060(±650), US\$4260(±294) and US\$1691(±676), respectively ($P = 0.001$), with 23%, 28% and 68% of the total incomes from annual sales of large ruminant, respectively. Of the farmers in XYL, XK and HP, 83%, 93% and 70% ($P = 0.009$) said their annual income increased compared with 2012, and 47%, 64% and 41%, respectively ($P = 0.005$), indicated this increase was from additional large ruminant sales. The study indicated that this large FMD vaccination programme was well regarded by participating farmers and may have provided satisfactory suppression of the disease in Laos, despite not achieving the preferred vaccination coverage. Continuation of the vaccination programme in FMD high-risk areas is suggested as desirable.

Introduction

Foot and Mouth Disease (FMD) is one of the most important global transboundary livestock diseases, compromising sustainability in livestock production and trade. With the majority of FMD outbreaks occurring in developing countries where veterinary capacities are sub-optimal and uncontrolled spread of FMD occurs, continuing epidemics of FMD have been described as a failure of the global food security system [1, 2]. In the Southeast Asian Region (SEA) including the Greater Mekong Sub-region (GMS), FMD mainly affects large ruminants and occasionally pigs, impacting on the livelihoods of smallholder farmers and national economies, particularly in the Lao People’s Democratic Republic (Lao PDR or Laos) [3, 4]. Although the FMD viruses (FMDv) have seven distinct serotypes (A, O, C, Asia 1 and SAT 1, 2 and 3), the co-circulation of multiple serotypes within zones of increasingly dynamic regional animal trade, led to groupings of isolates and countries into seven regional ‘pools’ [5, 6]. FMDv pool 1 includes the GMS, where recent epidemics have involved mostly isolates of O (Cathay, SEA Mya-98, Pan Asia), A (SEA 97) and less commonly Asia 1 serotypes [3, 7–9], although recently, outbreaks due to O/ME-SA/Ind-2001d and A serotypes have been emerging [10] suggesting that transmission of FMDv serotypes between pools is increasing.

In SEA, the inclusion of FMD vaccination activities in FMD control and eradication programmes proved successful in Indonesia and the Philippines [11]. However, control of endemic FMD in other SEA countries, particularly within the GMS where countries share porous borders with other FMD-endemic countries, is challenging [12]. Laos shares borders with five FMD-affected countries and is positioned on a major thoroughfare for transboundary livestock movements in the GMS, particularly from Thailand and Myanmar to China and Vietnam [9, 13], with over a million cattle now exported from SEA to China annually [14]. The Southeast Asia Foot and Mouth Disease (SEAFMD) campaign was launched in 1997, then expanded to include China (SEACFMD) in 2007, providing a ‘Roadmap’ that initially proposed a goal of achieving FMD freedom in SEA by 2020 [12]. The SEACFMD Roadmap describes the need for participating countries to improve their surveillance, early detection and reporting, rapid disease responses, plus contribute to improved understanding of livestock movement and trade in the region [9, 11, 12]. Gaining support for the SEACFMD programme from international donors to foster appropriate national animal health policies and cooperative leadership, plus influencing livestock stakeholders and especially smallholder farmers to

participate in vaccination programmes and improve biosecurity, is considered crucial for FMD control programmes to be successful in the GMS [14]. Improved understanding of both the financial constraints and opportunities of smallholder farmers, plus their attitudes towards FMD vaccination interventions, is considered important for achieving sustainability of FMD control in SEA. The socio-economic impacts of FMD on households likely influence the participation of farmers in vaccination programmes. This in turn has consequences for the sustainability of local and regional livestock trade, the developing livelihoods of farmers, plus consumer preferences for livestock products, thus impacting on regional national economies.

Between January 2012 and December 2016, the Department of Livestock and Fisheries (DLF) in the government of Laos received annual donations of FMD bivalent O and A and monovalent O serotype vaccines (initially <200 000 doses in 2012, increasing to 400 000 doses in 2015). This occurred mainly through the Stop Transboundary Animal Diseases and Zoonoses (STANDZ) programme funded from Australia and managed by OIE (The Office International des Epizooties or the World Organisation for Animal Health) Sub-Regional Representation for South East Asia located in Bangkok, Thailand, although additional vaccines were contributed by the Japan Trust Fund (JTF) of the OIE Regional Representation for Asia and the Pacific. The donated vaccines were used extensively in northern provinces, districts and villages of Laos that were considered as 'high-risk' areas for FMD transmission, particularly FMD 'hotspots' (areas where repeated FMD outbreaks have been recorded) and 'nodes' (areas where extensive animal trading occurs), such as transit routes for transboundary movements [9]. This programme was entitled 'The Foot and Mouth Disease Vaccination Project' and implemented in January 2012 in northern Laos, with expansion in early 2015 to include provinces in central Laos.

Following the completion of the vaccination programme in December 2016, an assessment of smallholder finances and their attitudes towards The FMD Vaccination Project was conducted. The study included detailed examination of farmer livelihoods to assess the role of livestock on household finances plus the roles of women in FMD control programmes. The study aimed to provide recommendations on future FMD control programmes in Laos and beyond, potentially providing benefits to the many nations at risk of endemic FMD in the SEACFMD network. This information is important to policy makers, livestock stakeholders and smallholder farmers, particularly where vaccination and biosecurity interventions are expected to be delivered by developing regional veterinary services tasked with providing effective and sustainable FMD control and eventually, eradication.

Methods

Survey location and farmer interview

The study used a mix of participatory approaches, building on tools developed for a recently completed study in northern Laos and those described in OIE regional office research guidelines [9]. The survey was conducted in January and February 2017, in the three northern provinces of Xayabouli (XYL), Xiengkhoung (XK) and Huaphan (HP) by a survey team of three persons, including the lead investigator, and a provincial and district staff member. These provinces were randomly selected from a list of 10 provinces participating in The FMD Vaccination Project. In each province, two districts ($n = 6$) and

four villages (two villages per district, $n = 12$) were randomly selected, based on the project participation list and consultations with local livestock authorities. Criteria for inclusion were they: (i) have been participating with The FMD Vaccination Project since commencement of the programme in January 2012; (ii) have considerable trading of large ruminants into and from the village; and (iii) have year-round vehicular access.

In each interviewed village, the interviews were conducted in two parts, each with different sets of questions that took approximately 45–60 min per interview (Supplementary material 1). The selection process for interviewees necessarily used a degree of convenience selection, particularly to accommodate farmer availability. However, to ensure that representative data were obtained from each village, the survey team facilitated detailed discussions with the village chief, elders and village veterinary worker prior to household selection.

First, the village chief, elders and village veterinary workers were interviewed 'face to face' with information collected to provide an overview of livestock health and production and recent and current vaccination programmes in the village. The questionnaires were designed to achieve satisfactory discourse analysis, as the low levels of literacy and ethnicity issues required a conversational format to encourage a free flow of information. The ensuing discussion obtained the total number of households in the village, the number of households with livestock, the number of households with livestock where a female headed the household, the number of farmers with livestock participating in the FMD vaccination, and records of cattle and buffalo vaccinated for FMD in the last round of FMD vaccinations. Due to limited resources for regular data collection and the dynamic nature of some data (e.g. number of calves), some information from some villages used an agreed estimated number derived during the detailed discourse.

Second, 12–16 smallholder farmers with cattle and buffalo in each village were interviewed 'face to face' ($n = 168$) with criteria for inclusion being: (i) the participating farmers have large ruminants; they may or may not have participated in The FMD Vaccination Project; and (ii) be willing to participate in the survey. Interviews included open questions followed by probing questions to clarify the answers and obtain the complete information required. Questions covered household financial status parameters (e.g. annual household incomes, number of large ruminants, number of animals vaccinated for FMD), farmer knowledge and attitudes on FMD and basic biosecurity practices, plus opinions on The FMD Vaccination Project.

Review of The FMD Vaccination Project and FMD outbreak records

FMD vaccination and FMD outbreak records between 2012 and 2016 available at the provincial livestock section and as reported to the DLF in Vientiane and the DLF regional office in Luang Prabang (LPB), were examined.

Data management and analysis

The smallholder farmer interview data were transcribed into spreadsheets in Microsoft Excel 2010. Their annual household incomes were classified according to livelihood activities, including income from cropping, small livestock animals (pigs, goats and poultry), large ruminants (buffalo and cattle) and other activities, including labour and trading, designated as 'other' as

previously described [3]. For the knowledge questions, responses were assessed based on answer guidelines developed by the research team. A correct answer was given one mark, and an incorrect or an 'I-do-not-know' answer was given a zero mark. Scores were added to obtain knowledge scores for each interviewed farmer with total marks of 7. Abilities of each farmer to answer questions on FMD correctly from the description of clinical signs were also obtained.

Quantitative variables (annual household income and number of large ruminants) were analysed using a restricted maximum likelihood (REML) in Genstat 14th edition statistical programme (VSN International), with province (XYL, XK and HP), gender of respondents (male vs. female) and gender of household large ruminant caretaker categories (male and female) as a fixed effect, and farmer identification as a random effect. Linearity, homoscedasticity and normality assumptions were checked by diagnostic plots of standardised residues of the quantitative traits on model checking options in REML. Dichotomous qualitative variables (yes/no answers) on responses to farmer attitudes and practices towards The FMD Vaccination Project were analysed using a χ^2 test. Comparisons between surveyed location (XYL, XK and HP) and gender of livestock caretaker and respondent categories were determined.

Data obtained at the village level included the means and standard errors of the number of: total households per village, households with livestock, households with livestock participating with The FMD Vaccination Project, the total livestock present and the total of livestock vaccinated for FMD, were summarised.

Data on FMD vaccination included the number of participating provinces, districts, villages and livestock vaccinated for FMD, from January 2012 to December 2016. The vaccination district and village participation (vaccine coverage) rates were determined based on the number of participating districts and villages, and the total number of districts and villages of the 10 participating FMD vaccination provinces, including Phongsali, Bokeo, Luang Namtha, Oudomxay, LPB, XYL, XK, HP, Vientiane and Xaisomboun [15]. It was unfortunate that the vaccination coverage rate at the animal level could not be accurately determined due to confounding of statistics [16] on the total number of adult animals in the participating provinces and districts.

Results

Numbers of interviewed farmers and their household rice production

The number of interviewed farmers and their household rice production by province categories were tabulated (Table 1). There were 168 farmers interviewed, with 95% of farmer respondents indicating that they produced enough rice for their household annual consumption.

Smallholder household annual and livestock incomes

There were significant differences in the farmers' total household annual incomes and income from cropping between the province categories, but no significant differences between the gender of livestock caretaker categories (Table 2). The mean total income per household in XYL, XK and HP were US\$5060(±650), US\$4260(±294) and US\$1691(±676), respectively ($P=0.001$), with 23%, 28% and 68% of the total incomes from the sale of large ruminants. Of the total interviewed farmers in XYL, XK and HP, 83%, 93% and 70% ($P=0.009$) said their annual income

had increased compared with 2012, and 47%, 64% and 41% ($P=0.005$), respectively, indicating that their annual income had increased from the sales of additional large ruminants.

There were no significant differences in the mean number of large ruminants per household between province and gender of livestock caretaker categories. The mean numbers of large ruminants per household were 10(±2.8), 12(±1.3) and 14(±2.7) in XYL, XK and HP ($P=0.7$), respectively. Of the total respondents in XYL, XK and HP, 73%, 85% and 87%, respectively, indicated that primary caretaker for their household large ruminants was either an adult or elderly male ($P=0.2$). Of the farmers in XYL, XK and HP, 92% 82% and 67% said that their total numbers of large ruminants had increased compared with 2012 ($P=0.004$) with the mean number increasing by 5(±4), 2(±2) and 3(±2) heads per household, respectively.

Farmer knowledge and attitude towards The FMD Vaccination Project

There were significant differences in farmer knowledge scores between province categories, but not between gender of respondent categories (Table 3). Of the interviewed farmers in XYL, 44% were able to answer FMD questions correctly ($P<0.001$), with 78% of the interviewed farmers in this province scoring ≤ 4 of the total of 7 marks ($P<0.001$).

There were no significant differences in farmer responses on their ranking of FMD vaccination and their interest in FMD vaccination, both by province and gender of respondent categories. Of the interviewed farmers, over 86% ranked the FMD vaccination activities as good and very good, with only one farmer in XK mentioning that the vaccination was not unacceptable ($P=0.4$, Table 3). Almost all farmers (100% in XYL, 96% in XK and 98% in HP) said they were still interested in the vaccination if some payment was required ($P=0.3$), and indicated they were able to contribute approximately US\$0.5 per dose (although the FMD vaccine and administration cost per unit is between US\$2.1–2.5). In XYL, 92% of farmers said that their livestock were vaccinated for FMD in the last 6 months ($P=0.2$), although about 75% of the interviewed farmers in this province said that their stock were regularly vaccinated for FMD every 6 months in the last 4 years ($P=0.03$).

Village-level FMD vaccination participation

The mean total households per village in the surveyed areas was 113(±78), with 90(±55) households with cattle and buffalo (Table 4). Of the total household with large ruminants, 60% (±9) participated in The FMD Vaccination Project, with 62% (±16) of the adult cattle and buffalo aged over 6 months vaccinated for FMD in the last round of vaccination. The village chief, village veterinary workers and elders all confidently said that the last outbreak of FMD in their villages occurred in early 2012.

Review of the FMD vaccination programme and FMD outbreaks

The record of available vaccines, source and serotype of vaccines provided for the programme were tabulated (Table 5). All vaccines provided from the STANDZ programme were bivalent serotypes O and A (Merial Company Ltd, Berkshire, UK) and vaccines from the JTF programme included both monovalent O and A serotypes (Merial Company Ltd).

Table 1. Survey location, number of interviewed farmers and their household rice production

Variables	XYL	XK	HP	Overall
Surveyed location				
No. interviewed districts	2	2	2	6
No. interviewed villages	4	4	4	12
No. interviewed farmers	59	55	54	168
No. interviewed female farmers	24	19	6	49
Mean age of interviewed farmers (years)	49 ± 11.5	47 ± 11.5	39 ± 11.7	46 ± 12.2
Mean size of farmer hh (pers./hh)	5 ± 1.4	6 ± 1.6	8 ± 3.1	6 ± 2.4
Mean no. females in hh (pers./hh)	3 ± 1	3 ± 1	4 ± 2	3 ± 1
Rice production				
Rice produced (tone/hh)	3.7 ± 3.0	4.7 ± 2.0	3.2 ± 1.6	3.9 ± 2.4
Cultivated areas (ha/hh)	1.3 ± 0.8	1.2 ± 0.5	0.9 ± 0.7	1.1 ± 0.7
Produce enough rice to hh (%)	91	96	98	95

XYL, Xayyabouli; XK, Xiengkhoung; HP, Huaphan; hh, household. Mean ± standard deviation.

The number of provinces, districts and villages participating in The FMD Vaccination Project was tabulated (Table 6). Since January 2012, FMD vaccination was implemented in the 10 provinces of Phongsali, Bokeo, Luang Namtha, Oudomxay LPB, XYL, XK, HP, Vientiane and Xaisomboun, covering 401 and 713 villages in the 2012 and 2016 rounds of vaccination, respectively, or approximately 21.8% (±7.9) of the total villages of the 10 participating provinces. All the vaccines were administered according to the manufacturer instructions by use of conventional syringes, with animals restrained individually using bleeding poles.

The number of cattle and buffalo vaccinated for FMD between January 2012 and December 2016 was determined (Fig. 1) providing an average annual combined vaccination for cattle and buffalo of 270 704 (±88 448). The number of animals vaccinated for FMD peaked in the period of August 2014 to February 2015, when over 370 000 cattle and buffalo were vaccinated.

The records of FMD outbreaks in the FMD vaccination sites and in northern Lao indicated the last recorded occurrence of FMD was in May 2013, although there were anecdotal reports of minor outbreaks of FMD occurring in central Laos in May 2015 and in northern Lao in Jan 2017.

Discussion

This study assessed the attitudes of smallholder farmers towards the large-scale FMD vaccination programme, plus changes occurring in smallholder household finances participating in The FMD Vaccination Project implemented in northern and central provinces of Laos between 2012 and 2016. It provides important information, indicating the majority of the farmers with cattle and buffalo appreciated this first large-scale FMD vaccination programme to implement in Laos, occurring at a time when positive financial benefits from their livestock were being accrued by these households during the 4-year period of the vaccination. A previously published partial budget analysis suggested that FMD vaccination programmes in Laos are likely to be cost-effective, with each dollar invested potentially achieving US\$5.3 in benefits [17], with net benefits at the smallholder farmer level of US\$22 for cattle and US\$33 for buffalo, following biannual FMD

vaccination [9]. Further, an earlier hypothetical study of the annual benefits of a regional FMD control programme involving vaccination in SEA, were estimated to exceed US\$70 million per annum, with a benefit cost ratio of 3:1 considered to outweigh the costs involved in achieving potential FMD freedom with vaccination by 2020 [18].

Vaccines are important in managing FMD as they assist in the suppression of virus transmission and debilitation of animals from clinical FMD, where oral and pedal vesicular lesions lead to inappetence and weight loss. Importantly, infected vaccinated animals excrete lower viral loads, limiting environmental contamination and subsequent challenge to naïve animals [19]. A field study conducted in 2009 of an extensive FMD outbreak in the Lao northern province of XK indicated that morbidity rates for a fully FMD vaccinated, compared with a partially vaccinated (50%) and unvaccinated, villages were 1.0%, 7.9% and 74.3%, respectively [20]. However, with increasingly dynamic livestock trade in the GMS and beyond, the risk of changes in circulating FMD serotypes appears to be increasing and as there is a limited cross-protection between FMDv serotypes, knowledge of the currently circulating serotypes is critical in the choice of vaccine(s) to use in the control of FMD [14, 21]. While several serotypes of FMDv can be included in a single vaccine, protection from all strains within those serotypes is not guaranteed [21, 22]. Recent outbreaks of FMD serotype O in northern and southern Laos in 2017 and 2018 (unpublished) and serotype O/ME-SA/Ind-2001d in April–May 2015 in Naxaythong district, Vientiane Capital in Laos, and Vietnam and Myanmar [10], plus serotype A in several countries in the GMS, have raised concerns of increasing risks of FMD due to use of vaccines that may offer limited protection against emerging serotypes [14]. Preliminary evidence from investigations of the outbreak of O/ME-SA/Ind-2001d in Laos suggests that transmission of FMD into the country is likely to have occurred due to movement of animal products from countries beyond the GMS.

This study provides evidence that a large FMD vaccination programme was well regarded by the participating smallholder farmers with the majority of the farmer indicating their willingness to contribute US\$0.5 per dose to the cost of future FMD

Table 2. Smallholder household income and their livestock, by province and gender of respondent categories

	Province categories				Gender of livestock caretaker/ Gender of respondent category*		
	XYL	XK	HP	P-value	Male	Female	P-value
Annual household income from: (USD/hh)							
Cropping	1441 ± 369	1678 ± 167	55 ± 384	<0.001	1105 ± 113	949 ± 239	0.6
Sale of small animals	133 ± 134	206 ± 61	272 ± 140	0.8	186 ± 38	272 ± 81	0.3
Sale of large ruminants	1178 ± 404	1207 ± 182	1148 ± 420	0.9	1184 ± 115	1149 ± 243	0.8
Others	2303 ± 465	1165 ± 210	218 ± 484	0.07	1254 ± 134	1286 ± 285	0.9
Total income	5060 ± 650	4260 ± 294	1691 ± 676	0.001	3728 ± 192	3665 ± 408	0.9
% of income from large ruminant sale to total income	23	28	68		31	32	
Has the annual income increased compared with 2012							
Yes (%)	83	93	70	0.009	82	84	0.7
Mean increased (%)	24 ± 21	23 ± 20	15 ± 14		22 ± 19	20 ± 19	
Annual income increased from							
Increased income from selling more stock (%)	47	64	41	0.05	53	45	0.3
Increased income from selling more agriculture product (%)	39	87	46	0.001	56	57	0.9
Increased income from non-agriculture activities (%)	53	65	63	0.3	58	57	0.2
No. cattle and buffalo (head/hh)							
Total	14 ± 2.7	12 ± 1.3	10 ± 2.8	0.7	12 ± 0.8	13 ± 1.6	0.7
Female cattle and buffalo	9 ± 1.9	8 ± 0.8	7 ± 1.9	0.8	8 ± 0.5	8 ± 1.1	0.8
Cattle	12 ± 2.7	9 ± 1.2	7 ± 2.8	0.6	9 ± 1.6	11 ± 0.8	0.4
Cow	8 ± 1.9	6 ± 0.9	4 ± 2.0	0.6	6 ± 0.6	7 ± 1.2	0.4
Primary large ruminant caretaker (%)							
Female	27	15	13	0.02	14	29	0.03
Male	73	85	87		86	71	
Has the number of large ruminants increased compared with 2012							
Yes (%)	92	82	67	0.004	79	84	0.5
Mean number increased (hd)	5 ± 4	2 ± 2	2 ± 3		3 ± 3	2 ± 3	
Has any cattle and buffalo been sold in 2016							
Yes	63	73	59	0.3	65	67	0.8
Mean number sold (hd)	2 ± 2	2 ± 2	2 ± 2		2 ± 3	1 ± 2	
Decision to sell livestock made by (%)							
Male	20	13	17	0.1	18	12	0.07
Female	6	2	0		1	7	
Together	73	85	83		81	81	
Money from livestock sell kept by (%)							
Male	18	14	37	0.009	29	7	0.007
Female	76	71	48		59	85	
Together	6	15	15		12	7	

XYL, Xayyabouli; XK, Xiengkhoung; HP, Huaphan; hh, household; hd, heads.

Predicted means ± standard errors, mean ± standard deviation.

*Annual household income and mean large ruminants were compared between gender of livestock caretaker whereas other variables were compared between gender of respondent category.

Table 3. Smallholder farmer knowledge, attitudes and practice responses towards FMD vaccination programmes, by region and gender of respondent categories

	Province categories				Gender respondent categories		
	XYL	XK	HP	<i>P</i> -value	Female	Male	<i>P</i> -value
Able to answer FMD (%)	44	82	34	<0.001	61	65	0.6
Farmer knowledge on basic biosecurity practices (/7)							
% scored ≤4	78	38	50	<0.001	53	63	0.2
% scored ≥5	22	62	50		47	37	
Morbidity and mortality in the herd reduced	83	87	80	0.6	80	92	0.5
Ranking FMD vaccination (%)							
Very good	67	71	74	0.4	68	78	0.5
Good	26	15	20		20	20	
Acceptable	7	13	6		11	2	
Not acceptable	0	2	0		1	0	
Would still be interested in FMD vaccination if some payment required							
Yes (%)	100	96	98	0.3	97	100	0.3
Mean amount willing to pay (US\$)	0.8 ± 0.5	0.5 ± 0.3	0.6 ± 0.6		0.6 ± 0.4	0.6 ± 0.5	
Stock vaccinated for FMD in the last 6 months							
Yes (%)	92	91	98	0.2	96	88	0.06
Mean animal vaccinated	8 ± 6.0	7 ± 4.2	7 ± 5.2		7 ± 5.4	6 ± 5.2	
% of the total adults	78 ± 32	87 ± 38	92 ± 21		89 ± 29	77 ± 35	
Stock vaccinated for FMD regularly in the last 4 years (%)	75	85	93	0.03	87	78	0.1

vaccination programmes, although FMD vaccine and administration costs per unit were between US\$2.1 and US\$2.5. In contrast, the small proportion of the interviewed farmer that ranked the vaccination programme as unacceptable may be a reflection that not all of their large ruminants were vaccinated for FMD. This was a direct result of the vaccination programme design that allowed only one day for vaccination of the whole village, resulting in some of the animals remaining unvaccinated.

Despite the high participation rate, the study identified that farmers had limited knowledge on basic biosecurity practices, with their inability to answer important questions on FMD from the disease description, consistent with a previous study conducted in early 2010 [23]. The current study confirmed the need for improved farmer knowledge of disease awareness and the importance of developing and implementing village-level biosecurity programmes to reduce the current and future risks of FMD outbreaks [14]. Further, lack of institutional credibility and the conflicting priorities of the official veterinary service and smallholder farmers have also been identified as barriers to prompt disease reporting [24].

Significant variation in household income from cropping, non-agricultural activities and total income between province categories was identified in our study, likely reflecting differences in socio-economic development between provinces in Laos [25, 26]. In the survey sites of XYL and XK, commercial maize cultivation is currently more prominent than in HP, due to high local demand and proximity to markets in Thailand and Vietnam,

respectively. Income from the sale of large ruminants of over US\$1,100 as observed in this study was similar to the US\$1040 reported previously [4]. These findings confirm that income from the sales of large ruminants continues to be very important to smallholder farmer livelihoods, particularly in the low-income households in HP where over half of their annual household income is derived from this trade. Improving cattle and buffalo productivity is increasingly recognised as a national priority in reducing reliance on shifting cultivation and addressing rural poverty in Laos. Programmes that support the development of the smallholder large ruminant sector, including FMD vaccination, offer important opportunities for alleviating rural poverty and food insecurity in impoverished rural communities in Laos [2, 17, 27].

Although the conclusions from this study do not suggest that The FMD Vaccination Project made a direct contribution to the increase of farmer income from large ruminant sales and increase number of large ruminant per household compared with commencement of the project in 2012, it is very likely that the program has significantly improved large ruminant health in the FMD vaccination areas, reducing the risk of both FMD outbreaks and debilitation of animals from clinical FMD, plus facilitation of safer trade. With estimates of financial losses incurred due to FMD outbreaks in early 2009 of US\$1.7 per cow for the fully FMD vaccinated village, US\$6.9 for the partially (50%) vaccinated village and US\$52.4 in the unvaccinated villages [20], it appears that a large opportunity cost is incurred where there is a failure to vaccinate in areas where the risk of FMD incursions is high

Table 4. Number of total household, household with livestock and their number of livestock vaccinated for FMD in the last 6 months, by province categories

Variables	XYL	XK	HP	Overall
Mean households (hh per village)				
Total households	210(±70)	96(±60)	88(±34)	113 (±78)
Households with cattle and buffalo	136(±47)	84(±55)	50(±31)	90(±55)
Households with cattle and buffalo participating in the FMD vaccination	56(±27)	53(±27)	37(±24)	49(±25)
Household with cattle and buffalo participation rate (%)	43(±18)	66(±7)	75(±13)	62(±9)
Mean number of cattle and buffalo (hd per village)				
Total	796 ± 394	444 ± 222	335 ± 181	525 ± 327
Cattle and buffalo aged >6 months	642 ± 312	360 ± 178	273 ± 146	425 ± 261
No. cattle and buffalo vaccinated for FMD	286 ± 144	257 ± 145	192 ± 99	245 ± 129
Vaccination rate (%)	44 ± 3	69 ± 13	73 ± 10	62 ± 16
FMD outbreaks				
Latest FMD outbreaks report (year)	2012	2012	2012	2012
Mean FMD outbreaks 2006–2016	2	1	1	2
Report the case	Yes	Yes	Yes	Yes
Means days reporting after knowing the case	2 ± 1	4 ± 3	5 ± 1	3 ± 2

XYL, Xayyabouli; XK, Xiengkhoung; HP, Huaphan; hh, household; mth, months; hd, heads. Mean ± standard deviation.

Table 5. Doses, source and type of FMD vaccines available 2012–2016

Years	Doses of FMD vaccines	Source	Type of vaccine
2012–13	620 000	OIE STANZ	Bivalent O and A
2012–14	400 000	OIE JTF	Monovalent O and A ^a
2014–16	600 000	OIE STANZ	Bivalent O and A
Total	1 620 000		

^aThese vaccines were only used in the provinces of XK and Vientiane.

and biosecurity awareness is low. Studies in northern Laos and southern Cambodia indicated that FMD caused financial losses to smallholders of 11% and 60% of their household annual income, respectively [9, 28, 29]. The major contributors to these financial losses due to FMD were losses due to morbidity, followed by the cost of treatment especially with antibiotics, plus mortalities in mainly young animals [9, 20].

This survey showed that over 75% and 93% of the interviewed farmers in XYL and HP said that their stock were vaccinated for FMD in the last 4 years, with over 62% of the adult cattle and buffalo at the village levels vaccinated for FMD in the last round of vaccination. This confirmed suspicions that not all adult animals received FMD vaccination and that some livestock were not regularly vaccinated for FMD during the last 4 years. It is also likely that the numbers of animals vaccinated may have been overestimated, particularly as in the early years of The FMD Vaccination Project, the recording system for numbers of animals vaccinated was not well established. In XK province where the monovalent vaccines were used initially, it is also likely that many animals were not vaccinated with both serotypes O and A. Further, it is considered that protection of the large ruminant

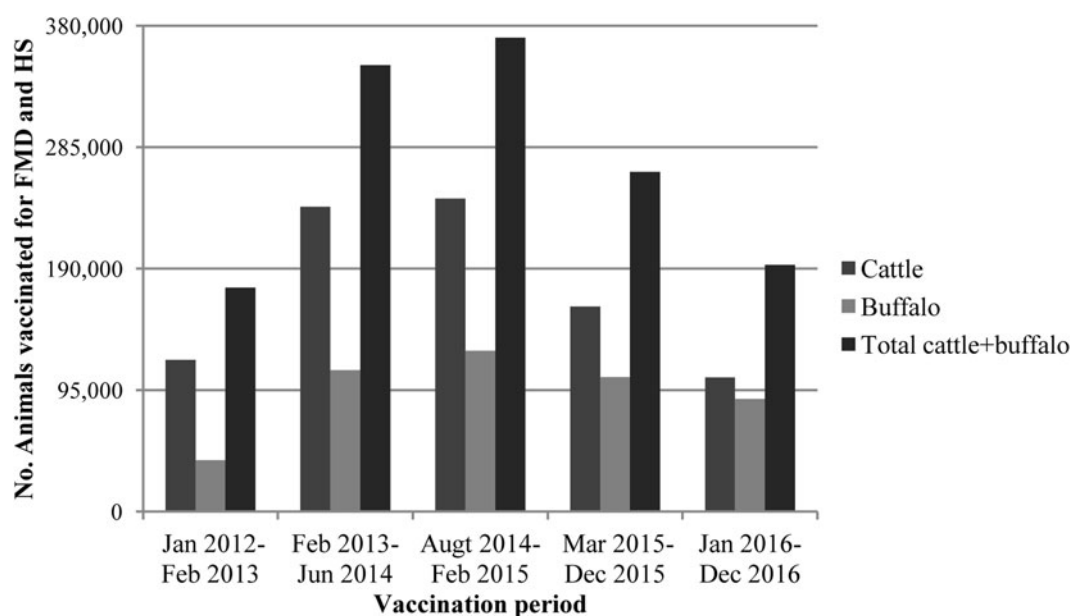
population by vaccination can be undermined by the rapid turnover of animals leading to the decline of herd immunity [30, 31], with high rates of trading of cattle from villages in Mekong countries previously reported [27].

Although there were no records of FMD outbreaks in these survey locations since May 2013, it is highly unlikely that sufficient herd immunity was obtained by The FMD Vaccination Project to provide optimal suppression of FMD. Vaccination coverage of >80% of herds to achieve an expected protection of >75% of animals (when sera from a group of 16-month-old revaccinated animals are examined) has been suggested as a desirable goal for FMD vaccination programmes [21, 31]. Effectiveness of vaccines and vaccination coverage are considered equally critical issues for successful FMD vaccination programmes [30, 31], as are efficiency of vaccine administration procedures and improvements in biosecurity [11]. Observations during The FMD Vaccination Project were that biosecurity training could not be delivered effectively to farmers during the vaccination procedures, largely due to both the limited time available because of the slow vaccine administration required where animal-restraint equipment is very basic (bleeding poles), and low smallholder herd numbers, requiring numerous farmers to be involved in assembling the village herd for the vaccination day. However importantly, the results of this study provide evidence that despite compromising their time for other farming activities, almost all farmers were supportive of the programme with many interested in making a financial contribution to the cost of future FMD vaccinations.

Obtaining and maintaining the trust of all stakeholders is critical for sustainable support of FMD vaccination programmes. This can be achieved by ensuring vaccine administration is optimal and using high-quality, efficacious FMD vaccines (multivalent if required) that are appropriate for the circulating serotypes, as identified by virological and serological studies enabling vaccine matching. Further, regular examination of the field efficacy of vaccine(s) in use, by serological methods that differentiate

Table 6. Number of provinces, districts and villages participating in the FMD vaccination programme, January 2012–December 2016

FMD vaccination period	No. participating provinces	No. total districts in participating provinces	No. total villages in participating provinces	No. vaccination districts	No. vaccination villages	Vaccination coverage by districts (%)	Vaccination coverage by villages (%)
Jan 2012–Feb 2013	8	64	4014	36	401	56	10
Feb 2013–Jun 2014	10	80	4152	68	1193	85	29
Augt 2014–Feb 2015	10	80	4152	60	1040	75	25
Mar 2015–Dec 2015	10	80	4152	59	1143	74	28
Jan 2016–Dec 2016	9	75	4057	29	713	39	18
Mean				50	898	65.7	21.7
s.d.				17	335	18.3	7.9

**Fig. 1.** Total number of cattle and buffalo vaccinated for FMD between January 2012 and December 2016.

infected from vaccinated animals (*DIVA*) during FMD outbreaks [32, 33], is advisable. Research knowledge gap analysis and direction of FMD vaccine development and use have been recently reviewed and indicate that independent evaluation of vaccine quality and monitoring of field protection to improve FMD vaccination control programmes are required [22]. Recent results of FMD vaccination monitoring in XK in Laos demonstrate that FMD serotype O vaccines induced appropriate response against FMD that were detectable even 15 months after the second vaccination [34]. This suggests that appropriate responses that protect against FMD are very likely to have been achieved in The FMD Vaccination Project sites, although this post-vaccine monitoring work is continuing and completed results are yet to be compiled.

Epidemics of FMD appear to occur in SEA every 5–7 years [7, 8]. A severe FMD epidemic occurred in northern Laos and beyond in 2010–2012 [3, 8], with numerous new outbreaks occurring in many neighbouring countries recently [14] but apparently not in

the northern provinces of Laos where The Vaccination Project occurred. With continuation of ‘informal’ livestock trade in the GMS, it is considered important to continue FMD vaccination in the region, conducted every 5–6 months and particularly in FMD ‘high-risk’ areas where FMD incursions may occur but outbreaks can be prevented by vaccine-induced suppression of FMDv [11, 12]. Continuation of FMD vaccination in northern and central Laos for at least another 2–3 years is advisable, ensuring that the momentum of FMD control in the region is sustainable and contributes to the suppression of potential outbreaks, particularly should prevention of FMD transmission and disease by attempted improvements in biosecurity fail. Continuation of FMD vaccination, improved surveillance with serological monitoring and FMD recording, plus enhanced biosecurity and response capability, are crucial to providing sufficient evidence for a potential application to OIE for an FMD free with vaccination zone in northern and central Laos, plus progression of Laos on the Progressive Control Pathway for

FMD in the future [35, 36]. It is noted that even with high-potency FMD vaccines with efficacies of 81–98%, suggestions are that vaccination should be conducted every 2.5 months, as beyond this period, vaccine efficacy will decline [22, 36, 37]. However, such an intensive regimen is unlikely to be practical in Laos due to limitations of vaccine funding, availability of human resources, plus the level of farmer participation and access to villages.

It is also widely acknowledged that in achieving more effective disease control, vaccination strategies should be supplemented with other disease control interventions, including improved biosecurity with animal movement control and quarantine, enhanced surveillance and reporting, plus public awareness campaigns that address FMD transmission risks [11, 14, 30]. Multiple interventions that improve large ruminant health and production and motivate interest in disease risk management through improved biosecurity [3, 8] are important in driving change in smallholder livestock production [27]. In addition, the identification of FMD high-risk areas ('hotspots and nodes') to enable more strategic use of vaccine, plus determination of the optimal number of vaccination rounds per year for smallholders, is highly recommended [11]. Further, regular active surveillance such as 'negative FMD reporting', immediate reporting of suspected new cases of FMD with development of an emergency response capacity to more effectively manage and limit outbreaks, regular laboratory confirmation of isolates for vaccine matching, plus provision of funding and human resources, are critical in achieving the best-practice FMD control strategies [11, 14, 38]. A number of these activities (e.g. 'negative FMD reporting') have been incorporated in the current national FMD control programme for Laos [39].

It is increasingly acknowledged that women have a very important role in managing rural family livelihoods and in caring for cattle and buffalo in Lao rural communities [4, 8, 40]. This survey identified that 14–29% of the interviewed farmers claimed that their livestock were managed by women, either the wife or an elder female member in the family. Further, 59–85% of the farmers indicated that women have a significant role in managing household finances, an observation similar to (or only slightly lower than) previously published observations [4]. This confirms that current and future extension activities requiring consideration of investments from household finances, such as purchase of vaccines, should encourage increased participation by women.

This study provides evidence that a large strategically targeted ongoing FMD vaccination programme was well regarded by the farmers, and despite not achieving optimal vaccination coverage and occurrence of some anecdotal reports of FMD occurring in central Laos, it may have provided sufficient suppression of FMDv to enable widespread protection from detectable disease outbreaks. Reflections on experiences from The FMD Vaccination Project identified numerous lessons learned of relevance to future FMD control and eradication programmes in SEA. This includes further attention to vaccination procedures to optimise herd immunity, increase vaccination coverage, enhance farmer participation plus ensure vaccine matching to enable protection against all current and emerging FMD isolates. In addition, lessons learned that could ensure that the momentum of FMD control in northern and central Laos is sustainable include:

- continuation of the vaccination programme every 5–6 months for at least another 2–3 years, particularly in targeted FMD high-risk areas;
- increasing vaccination days from 1 to 2–3 days per village to enable most of the adult cattle and buffalo in the village to be

vaccinated (this aims to increase vaccination coverage based on the observation that a field vaccination day would manage to vaccinate a maximum of 100–200 animals per day).

- increasing FMD vaccine availability and vaccination coverage, by providing FMD vaccines for village veterinary workers to continue vaccination in their villages (one or two 100 cc FMD vaccine bottles);
- provision of improved animal restraint facilities (supplementing the use of bleeding poles with portable yards and animal crushes) and superior vaccination equipment (using vaccine guns with protective sheaths to minimise self-administration) for district vaccination staff and village veterinary workers;
- consideration of payment of vaccinating staff by numbers of animals vaccinated per day or per trip (rather than a set per diem as used currently);
- improving the current data management system (i.e. number of adults animal in each village and district) to enable more reliable determination of FMD vaccination coverage;
- improved animal movement control and biosecurity practices including law enforcement for live animal and their products movement;
- strengthening active and passive disease surveillance and disease reporting at the village, district, provincial and national levels;
- continuation of two-stage random sampling serosurveys to provide increasing evidence of FMD control, eventually supporting a potential FMD-free zone with vaccination application to OIE;
- continuation of sampling and testing strategies to evaluate post-vaccination responses and ensure the importance of vaccine matching against emerging isolates is maintained;
- continuation of training programmes for vaccination staff and farmers on basic biosecurity to limit the risk of FMD transmission;
- increased attention to improve biosecurity in addition to vaccination, with biosecurity training programmes for farmers required and preferably delivered separately from the vaccination (due to time constraints);
- improved public awareness of FMD risks, transmission and prevention; plus provision of other production improvement interventions (e.g. forage plantation and utilisation, parasite control, farmer knowledge and practice training) to enhance livelihoods from livestock and generally promote a risk management philosophy throughout all levels of the livestock husbandry system in Laos and beyond.

Supplementary material. The supplementary material for this article can be found at <https://doi.org/10.1017/S0950268818002443>.

Acknowledgements. The study was conducted in compliance with State Acts and National Codes of Practice for Ethical Standards, with animal and human ethics approval obtained from The University of Sydney Ethics Committee (project no. 2015/765 and 2014/783, respectively). Financial support was from the OIE Sub-Regional Representation for South-East Asia (SRR-SEA) and the Australian-funded Stop Transboundary Animal Diseases and Zoonoses (STANDZ) programme, with some additional support from the Australian Centre for International Agricultural Research (ACIAR project AH/2012/067). The authors would like to acknowledge the collaboration from the staff of the SRR-SEA and provinces of Xayabouli, Xiengkhouang and Huaphan, plus the assistance of Mr Kong Khambounheung, Ms Bounxay Kinnavong and Ms Somly Chanda. The genuine hospitality and participation of all interviewed farmers, village chiefs and veterinary workers was greatly appreciated.

Conflict of interest. None.

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