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REGULAR ARTICLES

Improving smallholder cattle reproductive efficiency in Cambodia to address expanding regional beef demand

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Abstract This study aimed to identify factors associated with cattle reproductive output in rural smallholder farms in Cambodia in order to determine the main causes of reproductive failure and design efficient interventions for improvement. The majority of the nation's beef is produced on smallholder farms where productivity is constrained by poor animal reproductivity reflected in the recent livestock population decline of approximately 13 % from 2009 to 2013. Farmers ($n = 240$) from 16 villages from five provinces were surveyed in mid-2015 to determine their baseline knowledge, attitude and practices (KAP) associated with cattle reproduction. In addition, 16 case studies from three of these provinces were conducted to provide a more detailed assessment of current cattle reproductive husbandry practices. In order to assess the reproductive impact of previously implemented interventions, an endpoint KAP survey and longitudinal health and husbandry study from three Cambodian provinces conducted between 2008 and 2013 were also analysed. Three multivariable prediction models (two KAP and one longitudinal) identified the following significant factors associated with the reproductive outcomes 'number of calves born' or probability that cows 'gave birth': target feeding ($P = 0.074$), growing vegetables ($P = 0.005$), attitudes towards cattle vaccination ($P = 0.010$), improving bull selection ($P = 0.032$), local breed use ($P = 0.005$), number of joining attempts ($P < 0.001$), discontinuation of animal draught practices ($P = 0.003$) and retention of breeding animals ($P < 0.001$). The identification of significant factors and interventions in this study has led to intervention recommendations that can potentially improve reproductive efficiency, combat the declining cattle population and improve smallholder capacity to supply to expanding regional meat demand in South-East Asia and China.

Keywords Animal health · Biosecurity · Breeding management · Bull selection · Draught · Forage growing · Target feeding

Introduction

The expanding demand for beef in regional economies has seen rapid price rises. The producer price of cattle live weight has increased by 13.5 % per annum between 2007 and 2013 (FAOSTAT 2015), providing a significant opportunity for smallholder farmers to improve health and productivity of livestock. However, the Cambodian livestock sector is in decline with national cattle numbers having peaked at over 3.5 million in 2009 and have since decreased by almost 13 % to 3.05 million in 2014 (FAOSTAT 2015). Increasing smallholder income from enhanced livestock productivity can lead to important livelihood outcomes, as additional income is typically spent on increasing human food consumption (Ahuja 2012). This is significant as 42 % of rural children under the age of 5 currently suffer from stunted growth and 80 % of the population are rurally located and rely on agriculture for up to 90 % of income (National Institute of Statistics 2011, 2013, Pen et al. 2013, MAFF 2015). Livestock are also an important asset storage tool for the poor, with the farm gate value of large ruminants estimated at US$1.271 billion in 2010 (Young et al. 2014a) highlighting this significant national asset and potential for economic growth. Improving cattle reproductive

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efficiency may offer an important strategic approach to both improving farmer livelihoods and addressing food insecurity.

Reproductive inefficiency is accounting for the lack of replacement cattle with a longitudinal study by Young et al. (2014a) reporting mean inter-calving intervals (ICIs) of approximately 20 months in central and southern provinces of Cambodia. However, the calculation of ICIs excluded infertile females which constituted 60.3 % ($n = 1204$) of cows, indicating that actual average ICIs are longer. There are also reports of delayed age at first calving with a range of 2.5–4 years identified (Sath et al. 2008). Low productivity has been generally attributed to the dominance of rice production and income (Samkol et al. 2015) where cattle are retained as by-products to fulfil non-breeding roles, including provision of draught power; a source of income; a source of manure for fertilising fields; and as exchangeable assets in rural settings (Sath et al. 2008, Mong et al. 2013, Pen et al. 2013).

In traditional mixed farming systems, there are a wide range of potential causes of reproductive loss. Cattle frequently experience year-long malnutrition as they are reliant on rice by-products: rice stubble and rice straw, plus small quantities of 'cut and carry' native grasses collected from the roadside or paddy-line in the wet season (Sath et al. 2008, Maxwell et al. 2012, Mong et al. 2013). In smallholder systems, the low and variable quality of rice straw (Drake et al. 2002) combined with inadequate quantities of native grasses results in nutritional anoestrus (Diskin et al. 2003, Sartori and Barros 2011) which is exacerbated by the lack of calf weaning, practices by only 5 % of farmers (Serey et al. 2014). Endemic cattle diseases including foot-and-mouth disease (FMD), haemorrhagic septicaemia (HS) and internal parasitism are widespread due to poor farmer understanding of animal health issues, a lack of biosecurity practices, insufficient investment in disease preventive practices and weak provision of animal health institutional services (Young et al. 2013). The lack of bull selection, uncontrolled field mating, only 2.5–4.45 % of farmers castrating surplus bulls, inefficient oestrous detection and dry season calving (Sath et al. 2008, Serey et al. 2014) have also lacked proper investigation.

A recent development project 'Best practice health and husbandry of cattle, Cambodia' (BPHH) (ACIAR 2012) aimed to improve animal value in order to increase farmer income and meat supply through knowledge workshops and forage growing interventions. Programmes successfully increased cattle average daily gains (ADG) by 67 g (Young et al. 2014a) and reduced herd susceptibility to FMD outbreaks (Nampanya et al. 2012). However, reproductive outcomes displayed stagnant improvement with overall ICIs *not* significantly differing between higher intervention (HI) and low intervention (LI) villages (Young et al. 2014a). This suggests that current intervention programmes are failing to address important causes of reproductive failure. Hence, to bridge the gap between meat supply and demand, an investigation of factors and interventions associated with reproductive output is required in order to design effective interventions which address significant causes of reproductive loss. The current study is aligned with the project 'Village-based biosecurity for livestock disease risk management in Cambodia' (VBDRM) (ACIAR 2015) that commenced in 2015 and has identified improving smallholder cattle reproductive management as a primary objective.

Materials and methods

Site and farmer selection

Sixteen rural Cambodian villages were selected from five provinces; Battambang, Takeo, Siem Reap (four villages from each), Kbong Khmum and Kampong Cham (two villages from each) as Kampong Cham and Tbong Khmum were formally one province and officially split in 2013 (during project design). Village selection was based on set criteria including farmer, village authority and local government commitment to training and project work; ownership of 3–4 cattle per household; available land for future forage establishment; and reasonable proximity and year-round access to main roads, markets and cities.

Survey design and protocol to assess reproduction

The 2015 KAP survey consisted of four parts aimed at encompassing household aspects, knowledge, attitude and practices. Sections were further classified into four subtopics that included (1) animal health and biosecurity, (2) nutrition, (3) reproduction, and (where applicable) (4) livestock marketing.

The survey consisted of 60 closed-ended questions comprising multiple choice, one word responses or tables. Knowledge of cattle nutrition and reproduction was assessed by including questions on the effects of certain husbandry practices on pregnancy rates, health of calves born and dam body weight. Attitudes towards cattle nutrition and reproduction were assessed by including questions to gauge farmer interest in adopting new husbandry techniques which benefit cattle weight, number of calves born and quality of animals. Nutrition and reproductive management practices used were determined by asking farmers which animal feeds were used, the frequency of feeding, and method of bull selection for mating.

Surveys were conducted in project villages in July 2015 by randomly selecting 15 farmers from a total sample of 25–30 farmers per village, equalling a total sample size of 240 farmers. Surveys were carried out individually to avoid group conformity. The survey was written in English and translated into Khmer by Department of Animal Health and Production

(DAHP) staff. Prior to the survey, staff received training on survey content and implementation to control potential interviewer bias.

2015 case studies

Sixteen case studies were opportunistically conducted alongside 2015 KAP surveys when time permitted and farmers were available in three of the five project provinces: Takeo, Kampong Cham and Tbong Khmum. The case studies contained seven questions focused on breeding management, methods of detecting oestrous and pregnancy, length of inter-calving intervals, timing of calving season, age at calf weaning and the incidence of calf mortalities. Questionnaires were verbally translated from English to Khmer by DAHP staff at the time of interview and results were recorded on a case study answer sheet.

Previous BPHH project outcomes

An end-of-project KAP survey from 2012 and longitudinal dataset were analysed from the completed BPHH project as previously described by Nampanya et al. (2012) and Young et al. (2014a). Briefly, six paired villages from Takeo, Kampong Cham and Kandal provinces were designated as either high intervention (HI) or low intervention (LI). HI villages received 'formal training' including disease control and forage cultivation workshops; 'on the job' training led by extension staff including vaccine delivery and nutritional management, and 'applied field research' involving regular animal sample collections (including weight) over the course of 4 years.

Statistical analysis of reproductive outcomes

Three datasets (the 2015 KAP survey, the 2012 KAP survey, and the 2008–2012 longitudinal study) were cleaned in Microsoft Excel. Descriptive analysis, modelling and predictions proceeded in R software package (R Core Team 2015).

Descriptive analysis

Basic descriptive statistics from KAP surveys included means and standard deviations of key production variables. For longitudinal surveys, the total number of calf births per cow over the 4-year survey was calculated and the mean number of calves born per cow by 'age group' was determined. Age groups were expresses as 1-year-old cattle: 6–18 months; 2-year-old cattle: 18–30 months; and so on.

KAP survey variable filtering

All possible KAP explanatory variables were initially identified for development of Poisson generalised linear mixed models (GLMMs). The proxy variable 'number of calves born' (in the last 12 months per farmer) was used as the reproductive outcome variable in lieu of alternative indicators such as abortion rate or calving intervals, due to lack of records kept by farmers. Survey responses were quantified by allocating a score of '1' to the 'correct' or 'positive' farmer response and 'incorrect' answers or 'I don't know' were allocated '0'. KAP survey variables were organised into summary variables through principal component analysis (PCA) (Table 1). A criterion of 30 % variance accounted for was used to approve the first principal component (PC) as efficient summary variables. Filtering was undertaken to remove redundant variables. A correlation criterion of $r > 0.85$ was used to determine associated pairs and the variable least correlated to the outcome variable was removed. Leverage was assessed through the use of the 'moments' package in R software (Komsta and Novomestky 2015) to indicate skewness. A criterion of skewness >2 was used to identify positively skewed variables which were subsequently log-transformed. Log transformations were maintained if notable differences were observed between histograms of non-transformed and transformed variables. Variables were also removed if conformed responses were reported for more than 95 % of farmers.

Longitudinal study variable filtering

Longitudinal explanatory variables were identified for the development of a logistic GLMM. The binary response variable; 'gave birth' (in the interval between the last and present collection date) was allocated '1' to a successful birth and '0' to no birth. Explanatory variables were allocated binary responses of '1' for 'yes' and '0' for 'no', retained as categorical or allocated integers corresponding to options. Variable filtering proceeded as above.

Regression models for reproductive outcomes

The two Poisson GLMMs from 2015 to 2012 KAP surveys included two random effects: 'district' and 'village', whilst the logistic GLMM from the longitudinal survey had three: 'province', 'village' and 'animal ID'. Remaining variables underwent univariable analysis whereby a cut-off P value of 0.2 was used to determine inclusion into candidate predictor set for multivariable modelling. For the longitudinal dataset, variables with P values exceeding 0.2 in univariable logistic regression underwent an additional univariable two-way interaction analysis with 'age', and were dropped if the P values from two-way interaction exceeded 0.2. Backward elimination based on the Wald test was used to determine significant predictors of reproductive outcomes. Backward elimination stopped when all P values were <0.05 (exceptions were made for main predictors).

Table 1 Breakdown of summary variables derived from the first principal component in two knowledge, attitude and practice (KAP) surveys conducted in Cambodia

2015 KAP		2012 KAP	
Survey questions	First principal component	Survey questions	First principal component
Part 1	General information[a]	1–6	General information[a]
1–17	Disease knowledge[a]	7–22	Disease knowledge
18–20	Nutrition knowledge	23–28	Nutrition knowledge
21–24	Reproduction knowledge	29–33	Reproduction knowledge
25–29	Disease attitude	34	Information
30	Payment for FMD vaccine[a]	37–40	Disease attitude
31	Disease likelihood[a]	41	Nutrition attitude
32	FMD effect on value	46	Extension
33–34	Nutrition attitude	47	Activity participation (AP)
35–38	Reproduction attitude	48	Reason (for cattle keeping)
41	Farmer priorities	50–54	Disease practices
42	Information	55–57	Nutrition practices
43	Tractor[a]	60	Forage type
44	Fertiliser[a]	63–67	Forage practices
45	Draught[a]		
46	Bio-digester[a]		
47, 50–52, 54	Disease practices		
48–49	Disease prevalence		
53	Purchase livestock[a]		
55, 57	Nutrition practices		
56	Feed type		
58, 60	Reproduction practices		
59	Bull selection		

[a] Not incorporated into the first principal component

Results

Descriptive summary of production variables

In 2015 KAP surveys, farmers owned an average of 5.20 (SD = 4.42) head of cattle and had an average of 1.13 calf births per year (SD = 1.84) per household. This was higher than figures from 2012 KAP surveys where farmers owned on average 3.73 (SD = 2.24) cattle and experienced a mean 0.48 (SD = 0.72) calf births per year (Fig. 1). The most common rounded cow age group at enrolment of the BPHH project was the 'one' and 'two' year old cows consisting of 20.3 % (244/1204) and 18.3 % (220/1204), respectively (Fig. 2). 'One' and 'two' year at enrolment cows went on to have the lowest mean calf births of 0.07 (SD = 0.2) and 0.31 (SD = 0.56) respectively, per cow, over 4 years. The highest mean number of calf births over the 4-year project was 1.40 (SD = 0.63) which was derived from the 6-year-old cows at enrolment.

Animal health, nutrition and husbandry constraints

Key KAP survey summary statistics from 2012 to 2015 are presented in Table 2. Farmer knowledge in 2015 survey topics of nutrition, animal health and reproduction were consistently low with farmers scoring 25.1 % (0.75/3), 28.0 % (4.77/17) and 27.3 % (1.09/4), respectively. Rice straw was fed to cattle by 98.0 % (235/240) of farmers and fresh grass by 93.7 % (225/240) of farmers. Forage growing was under-utilised with farmers only devoting an average 0.12 ha (SD = 0.21 ha) to forage growing of a total farm area averaging at 2.58 ha (SD = 2.76 ha).

Prevalence of infectious disease was high with 25.0 % (59/240) of farmers reporting FMD infection and 21.2 % (51/240)

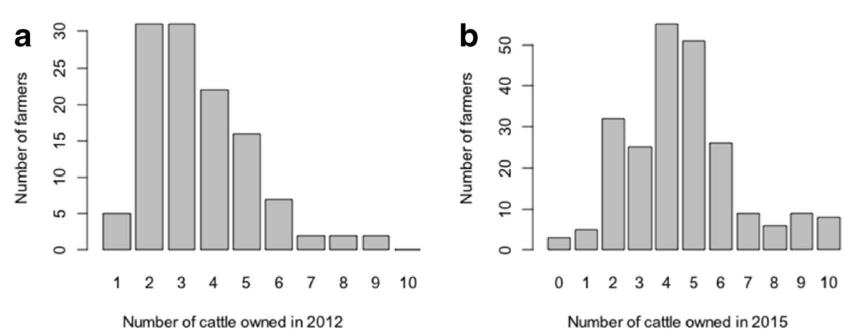

Fig. 1 Number of cattle owned by smallholder Cambodian famers in a **a** 2012 KAP survey and **b** 2015 KAP survey

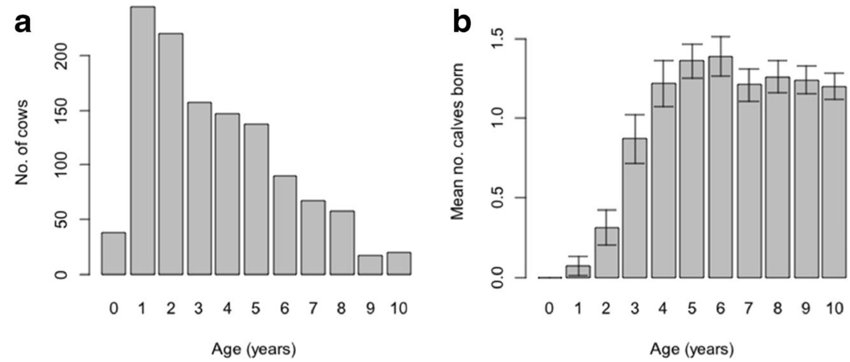

Fig. 2 Rounded age of cattle at enrolment in a 2008–2012 longitudinal study in Cambodia by **a** the number of cows per age group and **b** the mean number of calves born during the 4-year study

reporting HS infection in the last 12 months. Biosecurity was poor with 73.7 % (177/240) of farmers failing to practice quarantine, and 76.7 % (184/240) of farmers communally grazing cattle in the dry season. In addition, 85 % (204/240) of farmers confirmed they were willing to pay for FMD vaccination and 25 % (60/240) elected amounts ranging from US$1.25 to US$5 with an average of US$2.75.

Reproductive practices

Of the 16 case study respondents, 100 % reported that they bred their cows by bringing them to a village bull and paid a service fee that was typically US$10. When asked at what age farmers first bred their cows, 56 % (9/16) reported >2–3 years and 25 % reported 2 years of age. The main method of oestrous detection was visual observation of female vocalisation and mounting behaviour, with 92.9 % (13/14) of farmers reporting this method. Dry season calving was reported by 37 % (6/16) and 43.8 % (7/16) of farmers observed no seasonal trend. Farmers did not deliberately wean calves, but all (16/16) sold their calves at 6–9 months. Farmers could not accurately detect pregnancy with 62.5 % (5/8) reporting increase stomach size as the main detection method. Only 37.5 % (3/8) of farmers reported failure to return to oestrus after mating as their detection method. When asked if farmers had experienced deaths of calves, 75 % (12/16) of farmers reported none. Of the four farmers reporting calf deaths, three occurred within a week of birth.

Table 2 Findings from knowledge, attitude and practice (KAP) survey of farmers interviewed in Cambodia

	2015	2012
General		
Farmers interviewed	240	120
Household members	5.30 ± 1.72	4.78 ± 1.45
Mean economic parameters		
Land area (ha)	2.58 ± 2.76	0.90 ± 0.69
No. cattle	5.20 ± 4.42	3.73 ± 2.24
Forage area (ha)	0.12 ± 0.21	0.02 ± 0.04
No. cattle born	1.13 ± 1.84	0.48 ± 0.72
Mean knowledge scores		
Disease	4.77 ± 2.22 (/17)	10.12 ± 4.36 (/16)
Nutrition	0.75 ± 0.72 (/3)	3.89 ± 2.06 (/6)
Reproduction	1.09 ± 0.87 (/4)	3.66 ± 1.42 (/5)
Total	6.61 ± 2.74 (/24)	17.38 ± 8.26 (/27)

Mean ± SD; (/no. questions)

Predictors of reproduction outcomes

Significant predictors and effects on calf output from three datasets are presented in Table 3. The most significant nutritional predictors of the 'number of calves born' were garden size ($P = 0.005$), and farmer nutritional practice score (NPS) ($P = 0.074$), indicating that increasing area devoted to the garden and adoption of fattening pens for target feeding were associated with an increasing mean number of calves born per farmer. Improved animal body condition score (BCS), and increasing weight, strength and age recorded over the longitudinal study were also associated with improved reproductive output by significantly increasing the probability that a cow gave birth ($P < 0.001$, $P < 0.001$, $P = 0.040$, $P = 0.013$, respectively).

Increasing monetary amounts farmers were willing to pay for FMD vaccinations also significantly increased the mean number of calves born ($P < 0.010$) in 2015 KAP surveys and farmer disease knowledge and disease practices were highly correlated ($r = 0.96$) in the 2012 KAP survey.

Husbandry variables had significant effects on reproduction, with farmers who used animals for draught power significantly reducing their mean number of calves born ($P = 0.17$) and decreasing the probability of cows giving birth ($P = 0.003$) compared to farmers using tractors to cultivate land. The use of bull selection practices compared to no bull

Table 3 Significant predictors and relationship to mean number of calves born in the last 12 months per farmer or probability that cows gave birth in Cambodian households from three surveys

Predictor	Description	$b \pm$ SE	P value
2015 baseline KAP survey			
No. cattle	CB increased with increasing no. of cattle	0.058 ± 0.007	<0.001
Born no. poultry	CB increased with increasing no. of poultry	0.003 ± 0.001	<0.001
Sold no. cattle	CB increased with increasing no. of sold cattle	0.070 ± 0.022	0.001
VA	CB increased with increasing VA	0.001 ± 0.001	0.010
Draught	CB decreased when cattle used for draught	−0.427 ± 0.179	0.017
BRS	CB increased with increasing bull ranking score	0.113 ± 0.053	0.032
2012 endpoint KAP survey			
Log garden	CB increased with increasing garden area	1.391 ± 0.481	0.005
Log no. cattle	CB increased with increasing no. of cattle	3.199 ± 1.235	0.011
No. castrates	CB decreasing with increasing no. of castrates	−0.450 ± 0.196	0.024
No. calves	CB increased with increasing no. of calves	0.412 ± 0.197	0.040
NPS	CB increased with increasing NPS	0.658 ± 0.364	0.074
No. females sold	CB decreased with increasing no. of females sold	−0.258 ± 0.155	0.100
2008–2012 longitudinal survey			
Joining attempts	PGB increased with increasing joining attempts	1.520 ± 0.124	<0.001
BCS (4–1)	PGB decreased with increasing body condition score	−1.546 ± 0.270	<0.001
Bull selection	PGB increased in cows where bulls were selected	2.367 ± 0.434	<0.001
Nilzan treatment	PGB decreased with increasing Nilzan treatments	−2.840 ± 0.798	<0.001
Weight	PGB increased with increasing cattle weight	0.009 ± 0.003	0.001
Draught	PGB decreased when cattle used for draught	−1.972 ± 0.671	0.003
Breed	PGB increased for local cattle breeds	1.821 ± 0.645	0.005
Age	PGB increased with increasing cattle age	0.141 ± 0.057	0.013
Strength	PGB increased with increasing animal strength	0.535 ± 0.259	0.040

b regression coefficient, *CB* mean number of calves born in last 12 months per farmer, *PGB* probability that a cow gave birth, *VA* amount (Riel) farmers were willing to pay for FMD vaccine, *BRS* bull ranking score, *NPS* nutritional practice score, *BCS* body condition score

selection had a significant 11-fold increase on the odds of a cows giving birth ($P < 0.001$) as well as significant effects on mean number of calves born ($P = 0.032$). The ranking of bull 'temperament' was significant due to its high loading within the bull ranking summary variable (−0.79). Increasing the number of joining attempts per cow significantly increased the probability that cows gave birth ($P < 0.001$) and every additional joining attempt resulted in a fivefold increase on the odds of a cow giving birth.

Herd structure and breed had reproductive impacts as the increasing the number of castrates ($P = 0.024$) and sold females ($P = 0.100$) resulted in a reduced mean number of calves born. Although, increasing overall cattle numbers per farm was associated with increasing mean number of calves born in 2015 ($P < 0.001$) and 2012 surveys ($P = 0.011$). Local breed cows had a significant sixfold increase on the odds of giving birth ($P = 0.005$) relative to the hybrid local and Haryana crossbreed animals.

Random effects were not significant as estimated variance components were not nominally significantly different from zero. There were no significant interactions between predictor variables and 'age'.

Discussion

As far as we are aware, this is the first reported study analysing factors associated with the reproductive output of Cambodian cattle which is important as factors limiting reproduction are specific to breeds and prevailing environments. The study recommends interventions to improve nutrition and animal health, promote bull selection and adoption of mechanical draught and optimise the joining protocol based on associations found between reproductive outcomes and KAP and animal health variables. Other interesting findings were the high correlation between farmer knowledge and practices ($r = 0.96$) highlighting knowledge as a valuable resource in facilitating improved productivity. A changing enterprise focus was also observed as an increasing number of cattle were acquired by livestock keepers and farmers were more willing to pay for vaccines. This signifies shifting farmer priorities which favour livestock production and potentially reflect improved receptivity to development interventions.

Nutritional interventions are recommended due to the vast underfeeding identified in study villages. Farmers predominantly fed cattle rice straw and fresh grass (98.0 %, 93.7 %

respectively) in 2015 which provides low crude protein (CP) comprising 2–7 and 13.1 %, respectively, and metabolisable energy (ME) of 4–6.5 MJ/kg DM and 7–11 MJ/kg DM, respectively (Drake et al. 2002, Nour 2003, Samkol et al. 2015). Low CP intake in the first trimester can reduce the size and density of ovarian follicles of heifer offspring and impair long term herd fertility (Sullivan et al. 2009). Hence, growing improved forages and target feeding females may enhance baseline animal nutrition and reproductive potential.

Cambodian farmers can successfully adopt forage growing, with adoption rates of 77 % reported across six Cambodian villages from 2008 to 2011 and resulted in significantly improved animal ADGs (Nampanya et al. 2012, Bush et al. 2014b). Established agrarian skills were deemed vital in facilitating initial success and subsequent adoption by neighbouring farmers and the positive association identified in this study between garden area and mean calf births ($P = 0.005$) confirms this relationship. Forage growing area was not significantly associated with calf output in this study possibly due to newly established project villages having a low forage area of 0.12 ± 0.21 ha/farm. However, it remains a relevant intervention for improving reproduction based on the positive relationship observed between increased animal live weight and the probability of cows giving birth ($P = 0.001$).

Target feeding was positively associated with increasing mean number of calves born in this study ($P = 0.074$) and can potentially address the low productivity of young breeding females. Heifers aged 6–18 months at longitudinal enrolment comprised the largest age group of breeding females yet displayed the lowest mean number of calves born of 0.07 ± 0.29 per cow over 4 years (Fig. 2). This is partially attributed to the majority of farmers (56.3 %) not attempting mating until animals are 2–3 years old, coinciding with increased animal capacity to utilise lower quality feed for reproduction and growth (Wayman et al. 1973). Targeted nutrition can address heifer unproductivity by reducing the age of 60 % adult weight attainment required to induce puberty (Abeygunawardena and Dematawewa 2004) and by enhancing maternal calving weight which improves reconception rates (Schatz and Hearnden 2008). Approximately 800–1000 m^2 of forage area per animal is recommended to ensure animals are target fed at 15% body mass required to achieve significant live weight gains (Bush et al. 2014a). However, considering the land availability constraints in many smallholder farms, 400 m^2 forage plots and target feeding one animal over a 12-month period has been recommended (Ashley et al. 2016). Furthermore, target feeding at 8 % body mass for 3 months has been reported to increase live weight by 25.9 kg and importantly, increased animal value by US$60 which provides economic incentives needed to encourage farmer adoption (Page et al. 2013, Bush et al. 2014b).

Interventions to control disease are strongly recommended in Cambodia due to the high FMD and HS incidence reported by farmers in the last 12 months (25.0 and 21.2 %, respectively) and because FMD vaccination was significantly associated with mean number of calves born ($P = 0.010$). The majority of surveyed farmers (85 %) ($n = 240$) were willing to pay for cattle vaccinations signifying increased awareness of the associated cost-benefits. On average, farmers were willing to pay US$2.75 for FMD vaccinations ($n = 60$), and increasing amounts elected corresponded to improved reproductive output. The estimated cost of biannual vaccination in Cambodia is US$2.44 (Young et al. 2013) and the alignment to values elected by farmers suggest that the 25 % of farmers reporting figures are currently vaccinating. This strongly suggests FMD vaccinating improves large ruminant reproductive potential. Although village-wide vaccination programmes can prevent FMD and HS outbreaks in Cambodia (Nampanya et al. 2012), it is recommended that programmes are accompanied with biosecurity interventions as approximately 75 % of surveyed farmers fail to quarantine introduced animals and allow communal cattle grazing. Both procedures have been identified as the two most risky FMD practices in neighbouring Thailand (Cleland et al. 1996). However, in order to take advantage of improved farmer attitudes towards FMD vaccinations, biosecurity and vaccine availability and will need to be addressed in future research for development.

The sixfold increase in the probability of indigenous yellow cattle giving birth to offspring compared to exotic crossbreeds ($P = 0.005$) conveys the importance of genetic adaptation to the local environment. Despite the improved production potential of exotic breeds, it appears their genetic advantages are being offset by their lack of adaptability to tropical environmental stressors, and a lack of forage development, concentrates and animal health services (Köhler-Rollefson et al. 2009, Martojo 2012). As indigenous cattle have not undergone genetic selection to the same magnitude as their exotic conspecifics, promoting local breed selection may enhance their production potential. Combined with fundamental breeding training, such as record keeping and preventing inbreeding, local breed improvement may prove to be a more sustainable alternative to exotic breed introductions in Cambodia. Additionally, the practice of bull-selection for breed improvement can increase the probability of cows giving birth by a significant 11-fold. However, appropriate trait selection is equally important as farmer selection for calm bull temperaments over body size, fertility, and price, can actually significantly compromise annual calf output ($P = 0.032$). Whilst calm bull temperaments promote easier handling during joining, docile temperaments can indicate lowered social dominance and siring ability (Plusquellec and Bouissou 2001, Whitworth et al. 2008). Hence, it is recommended that knowledge interventions promote the importance of siring ability and body weight in order to accelerate bull puberty attainment, and increase testicular health and sperm quality (Larsen et al. 1990, Cumming 2006, Whitworth et al. 2008).

Breeding management should be a priority for future interventions due to four joining attempts being required for cattle to maximise calving probabilities ($P < 0.001$). This infers three prior fertilisation failures which extend calving intervals by a minimum 63 days. Extended post calving anoestrus is a potential cause of failed reconception and is strongly influenced by the degree of emaciation incurred during lactation (Kanuya et al. 2006). In Cambodia, where mean lactation BCS is a low 1.8 (Samkol et al. 2015), gestational nutritional is one potential area requiring improved management to enhance conception rates. This will include avoiding dry season calving which was practices by 37.0 % of case study farmers. Additionally, low live weight is associated with reduced corpus luteum size (Vandehaar et al. 1995) resulting in decreased oestradiol release and discrete behavioural oestrus (Bó et al. 2003, Solano et al. 2005, Sartori and Barros 2011). This is potentially contributing to oestrus misdiagnosis as 92.2 % of case study farmers rely on behavioural oestrus to prompt joining. Hence, improving joining success in order to reduce ICIs will require improved breeding management including enhanced gestational nutritional and improved oestrus detection.

Wider adoption of draught mechanisation is needed to reduce the number of castrates maintained by farmers as they divert nutrients away from breeding females and are associated with a reduced mean number of calves born ($P = 0.024$). A retention of draught animals also potentially increases the number of sold breeding females, which is a suggestive factor reducing calf births ($P = 0.100$), or contribute to increasing herd size. Average cattle numbers per farmer have increased from 2012 (3.73 ± 2.23) to 2015 (5.20 ± 4.41) as displayed in Fig. 1. Although increased numbers inevitably increase the mean number of calves born ($P = 0.001$, $P = 0.011$), the actual productivity per animal remains concerningly low with annual mean calf births only increasing from 0.475 ± 0.72 in 2012 to 1.13 ± 1.84 in 2015, which is not proportionate to increased herd size. Therefore, this study recommends the retention of fewer animals as high density herds can suffer reduced reproductive efficiency per animal (Pen et al. 2013) which increases methane intensity and the carbon footprint of smallholder farms (Hristov et al. 2013). Installation of mechanical draught power can replace castrates and exotic cattle in order to reduce herd size and improve nutritional availability for breeders. However, due to historical preference for exotic crossbreeds for improved asset value and superior draught ability, divergence from crossbreeds will require visible productivity cost-benefits.

Other interesting findings were that poor practices relating to animal nutrition, health and husbandry were reflected in low knowledge scores in 2015 KAP survey across all farmers with mean scores of 25.1, 28.0 and 27.3 %, respectively. This can be improved through knowledge workshops and training which have previously shown to significantly improve farmer reproductive knowledge from 48.7 to 97.7 % (Young et al. 2014b). The fact that farmer knowledge and practices were highly correlated ($r = 0.96$) reflects the application of knowledge based interventions in facilitating adoption of best practices.

Although animal health, nutrition and husbandry constraints in rural smallholder production systems present a wide range of potential causes for reproductive loss, their effects have not been explored in detail and previous interventions have targeted nutrition and disease without producing marked reproductive improvement. The study recommends a series of key areas for inclusion in future intervention programmes to increase reproductive efficiency within smallholders which is needed in order to address the rapidly increasing red-meat demand. As the Cambodian livestock industry gradually transitions into a demand driven system in response to the enhanced consumption of red-meat in South-East Asia and China, increased reproductive efficiency is needed to ensure this transition is sustainable leading into the future.

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Conflict of interest The authors declare that they have no conflict of interest.

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