

Impact of forage introduction on cattle grazing practices and crop–livestock systems: a case study in an upland village in northern Laos

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Abstract. Lao smallholders are experiencing livestock grazing land constraints due to resettlement, increasing cattle numbers and commercial cash crop plantations. In this paper we describe changes in cattle grazing systems in an upland village in northern Laos, including the role of forage crops and their effects on cattle productivity. We interviewed 92 Hmong and Khmu households about their migration history, cattle grazing practices, cattle productivity and other livelihood activities. In addition, we measured the heart girths of 231 cattle. We found that the traditional free-range cattle grazing has diverged into three distinct systems incorporating fields fenced to different degrees. Although none of the three systems increased cattle body size, the forage pasture and swidden-farming system successfully increased the grazing capacity compared with other systems. Thus, this method appeared to be the most suitable for Hmong smallholders to manage crop and cattle production in the context of land constraints. Efforts should be made to examine how the newly implemented systems could attenuate villager livelihood and pre-emptively address the problems associated with degrading fallow land.

Additional keywords: crop–livestock system, forage, land use, rotational grazing, swidden farming.

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Introduction

Smallholders in South-east Asia have long relied on the crop–livestock systems that integrate large ruminants, such as water buffalo and cattle, into subsistence-oriented crop farming (Devendra and Thomas 2002; Stür *et al.* 2002). Upland and lowland rice cultivation results in fallow natural vegetation that is used for extensive free-range feeding. Ruminants provide food protein and labour as draught animals, thus serving as a valuable asset that can act as a safety net for households (Vien *et al.* 2006). However, smallholders experience livestock feed and water deficiency during the dry season, and restrictions of free grazing in the wet season to avoid crop damage (Devendra and Thomas 2002; Phonvisay *et al.* 2016).

Regional socioeconomic changes (increasing population pressure on land use, shorter rotations, village resettlement, intensification of cropping, and livestock production) have necessitated fundamental changes to the historical crop–livestock systems (Roder 2001; Bouahom *et al.* 2004). Population increases in south-east Asia have led to shorter rotations for swidden agriculture and lower crop yields (Cramb *et al.* 2009). In an effort to enhance rural economic development and conserve natural resources, each household is now

designated a set amount of arable land, thus limiting the cultivation area (Thongmanivong and Fujita 2006) and raising the population pressure (Jones *et al.* 2004). Economic development has also focussed on the introduction of cash crops (e.g. rubber-producing plants) to replace the traditional swidden farming. This shift shrinks the fallow vegetation area, and so decreases the amount of land suitable for cattle grazing (Takai and Sibounheuang 2010). Simultaneously, the region has seen an increase in demand for beef and a concurrent rise in cattle prices. As a result, cattle farming has become an increasingly important income source for smallholders (Huyen *et al.* 2010).

The inevitable land-use conflicts between large ruminant farming and cash crop cultivation are causing multiple issues in northern Laos. For example, the number of water buffalo has decreased (Takai and Sibounheuang 2010), and some buffalo owners have been forced to sell their livestock in order to avoid conflict with rubber plantation owners. This problem has exacerbated as the Lao government implemented land-use zoning to stabilise swidden farming, diminishing the fallow forests where water buffalo were allowed to graze freely. Indeed, smallholders in Laos had difficulties expanding their holdings because of these land constraints (Harding *et al.* 2007). It is

difficult for the traditional Lao crop–livestock systems to co-exist with the shifting land uses occurring under modernisation.

One potential solution is to change cattle grazing systems through the introduction of forage crops that can be used for intensive grazing by livestock and reduce the amount of labour required to collect wild vegetation (Millar and Photakoun 2008). Changes in feed directly affect cattle health and bodyweight (Peters *et al.* 2001). On-farm fattening experiments conducted in northern Laos demonstrated that the farm-fattened cattle had growth rates eight times higher than the free-range cattle (Nampanya *et al.* 2014). Studies from Vietnam, where farmers are increasingly using forage crops, indicate that stall feeding and fattening techniques (cutting and carrying forage to penned livestock) have decreased the need for labour and have improved cattle productivity (Huyen *et al.* 2010; Stür *et al.* 2013).

Lao farmers employ a variety of pasture management practices, cattle raising methods, and seasonal combinations to ensure sufficient feed sources (Phonvisay 2013). However, few studies have examined variation in grazing systems across wet and dry seasons in relation to cattle productivity (Pravongviengkham 1998; Horne and Stür 1999; Nakatsuji 2010; Takai and Sibounheuang 2010; Shirai and Yokoyama 2014; Phonvisay *et al.* 2016). The aim of this study was to investigate the relationships between multiple grazing systems and cattle performance. First, we demonstrate how land constraints have altered cattle grazing systems, while accounting for seasonality; second, we evaluate the effect of forage crops on grazing systems and cattle productivity; and finally, based on our findings, we discuss a plausible future for crop–livestock systems for upland villages in northern Laos.

Research site

The study took place in Pong Pao village in the Phonxay district of Luang Prabang Province, ~80 km from the provincial capital. Although Pong Pao is not particularly remote, it does share other characteristics that are typical of upland villages in northern

Laos: it is inhabited by Hmong and Khmu; the systems of farming include swidden farming and raising cattle; and migration and land constraints are issues for the village. These are common issues and, therefore, the conditions of this village can be seen as representative of upland villages in northern Laos (Fig. 1). The village is ~400 m above sea level, and is surrounded by mountains ranging from 1000 to 1400 m in elevation. Distinct wet and dry seasons occur from May to September and October to April respectively. Temperatures are higher in the wet season (the highest 41°C in May 2014) and lower in the dry season (the lowest 7°C in January 2014) (Fig. 2).

As of 2016, the village population was 826, with 132 households (Table 1). Most villagers belonged to the ethnic groups, Hmong and Khmu; these are the predominant ethnic groups in northern upland Laos (Epprecht *et al.* 2018). In 1997–1998, the number of Khmu households was 28, of which 16 moved away before 2003 (LSUAFRP 2003). This movement was confirmed by interviewing villagers, who stated that most Khmu households originally residing in the village had moved to central Laos. Of the 40 Khmu households surveyed in the study, all except five, immigrated to the village after 2000 (Table 2). Most current Hmong households moved during 2000–2004 from villages at relatively high elevations in the surrounding mountains (e.g. Pha Toop, Phou Soong Noy and Phou Ja Norm) (Fig. 1; Table 2). Villagers described a clear difference in migration patterns between the Hmong and Khmu groups. The Hmong immigrated as a village unit, whereas the Khmu did so in household units from multiple villages. Consequently, the Hmong group can be divided into three subgroups based on their village of origin from which the migration took place following the village merging program of the government to move people to closer to the road and other infrastructure facilities (LSUAFRP 2003).

The Hmong and Khmu groups differ in their historical and current agricultural production methods, including the amount and type of livestock (Table 1). In their traditional villages before migration, generations of Hmong households grew high-value

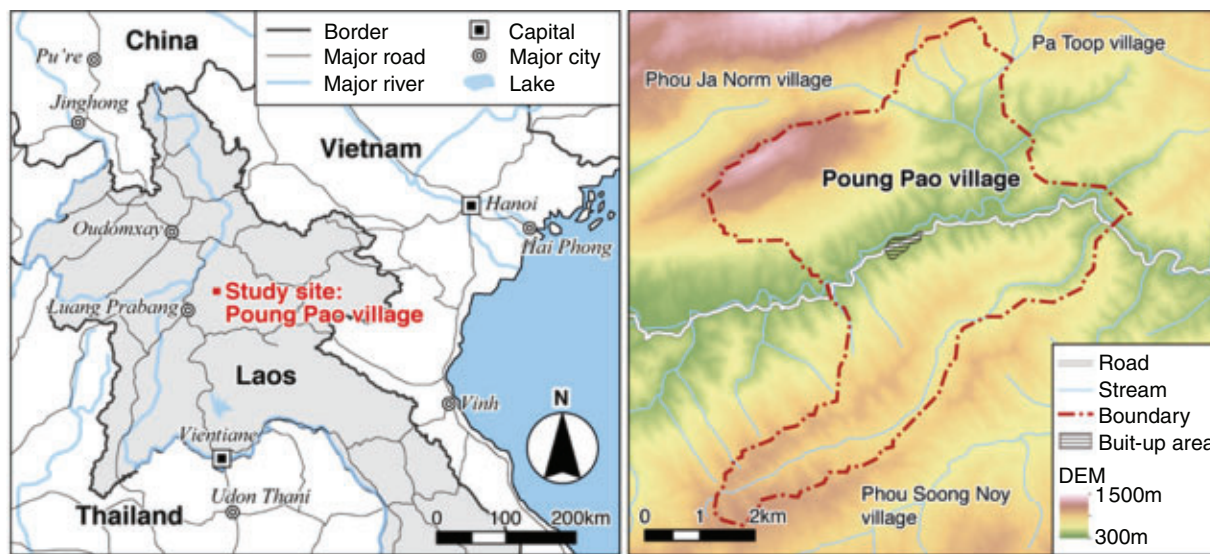


Fig. 1. Study site location and surrounding villages.

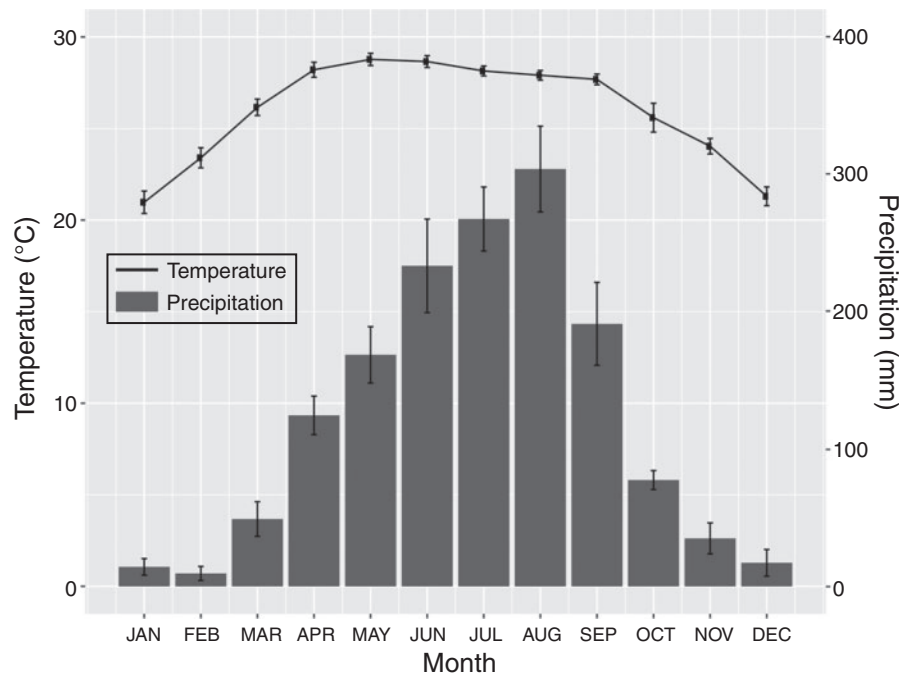


Fig. 2. Mean monthly temperature and precipitation during 2004–2015 in Luang Prabang Province.

Table 1. Population, number of total households, and number of the sampled households in Pong Pao, grouped by ethnicity

Description	Hmong	Khmu	Lao	Total
Population	518	286	22	826
Total households	79	47	6	132
Sampled households	52	40	0	92
Households with cattle	51	8	0	59
Households without cattle	1	32	0	33

Table 2. History of household migration by ethnic group

Year of immigration	Hmong	Khmu	Total
Born in Pong Pao	0	5	5
Before 2000	2	2	4
2000–2004	40	12	52
2005–2009	6	6	12
2010–2015	4	15	19
Total	52	40	92

opium and owned cattle as their primary livestock. Cattle are preferred because of their resistance to cold and general tolerance of conditions at higher elevations. Moreover, the Hmong group live in regions with large grazing areas suitable for cattle. In contrast, the Khmu households tend to raise small livestock, such as poultry, because their lower-elevation villages contained less available grazing land (Schlemmer 2002). These historic settlement preferences (Sodarak 1999) have meant that the Hmong households have greater assets and are more often able to buy agricultural land and other necessities when settling in a new

village (Table 1). The Land-Use Planning and Land Allocation program (LUPLA) was established in the early 1990s. Since then LUPLA has become one of the main elements of Laos' land-use planning system. In its early form – often referred to as Land and Forest Allocation (LFA) – the program involved identification of the village boundaries and demarcation of the land to be conserved or regenerated as forest. The process became gradually more elaborate, involving the individual allocation of agricultural plots to village households and the zoning and mapping of the village land. The individual allocation of agricultural plots to village households meant a household has the land-use right of their agricultural land particularly for swidden farming (Lestrelin *et al.* 2012).

Government efforts to provide public service and infrastructure, have drastically changed the ethnic composition in Pong Pao. Populations in small villages have been encouraged to move to live near roads and basic infrastructure, e. g. through the 1997–1998 LUPLA program. These programs restricted the amount of arable land that villagers could use, limiting the ability of villagers to subsist off the mixed-farming livelihoods. Then, in 2000, 28 Khmu households in Pong Pao were allocated 150 ha land, which was divided into 133 plots, and the village authority received 437 ha. This is the land area that can be allocated to communal grazing areas, crop cultivation and swidden farming for any new households who claim agriculture land (LSUAFRP 2003). These changes led to an emigration of the Khmu households, who sold their allocated land to other villagers. Other Khmu households immigrated to Pong Pao, attracted by the promise of arable land, electricity, water, and other services. Simultaneously, the Opium Elimination Strategy prohibited the Hmong households from growing opium in the mountains, causing a move down to the village. Unsurprisingly,

this increased population concentration resulted in disputes over land use (Jones *et al.* 2004). One notable consequence of these conflicts was increased cattle mortality, causing the Hmong households to move their cattle back to their original villages (LSUAFRP 2003). Hence, Hmong have more cattle than Khmu.

To address the issues related to cattle production, LSUAFRP, a joint rural development effort of the Lao government and Swedish International Development Agency (SIDA), introduced forage crops and cattle fattening techniques to Pong Pao during 2005–2006. The project freely distributed the seeds of several forage types (Ruzi grass, Napier grass, Stylo kegun and Mulato grass), educated villagers on cattle production and designated a fenced communal field to grow fodder. Cattle were allowed to graze in this field for several months after establishment of forage species. In addition, villagers were encouraged to fatten their cattle using the cut-and-carry system, where cattle were tethered in stalls within the settlement area and supplied with forage. Immediately after these methods were introduced, eight Hmong households started the cut-and-carry system, and this number increased to 23 by 2010, whereas other Hmong households employed free-grazing.

Methods

A mixed research methodology (including quantitative and qualitative methods) was used in this study. A focus group discussion with the village committee and cattle raiser group was conducted in May 2016 to obtain the viewpoints of the villagers with regard to their livelihoods. Semi-structured household interviews were then conducted in August 2016 with 92 out of the 132 households in the village were randomly selected households who are available in the villages at the time of survey and willingly to interview (Table 1). Households were interviewed regarding the composition of the family, migration history, sources of income, agricultural practices (swidden-farming, plantation of rubber, teak, cash crops), and land use. The income sources were grouped into four categories: cattle, other livestock, cash crops, and off-farm work. All cattle were of the indigenous yellow breed widely domesticated throughout East and South-east Asia (Namikawa *et al.* 2000; Wilson 2007) and genetically closest to the Vietnamese local cattle (Nomura *et al.* 2000). Other livestock included buffalos, pigs, poultry, and goats. The cash crops consisted of Job's tears, sesame, maize, and rubber. The off-farm income involved hired labour for agricultural work, collecting non-timber forest products, construction, trading, and salaries or pensions from previous work. The swidden-farming practices, forage cultivation, and land acquisition methods such as inheritance, purchasing, rent, and allocation were also recorded.

In August 2017, data on the heart girths, age, sex and owner identity of 231 cattle were collected. The measurements were made for all cows in a household, if there were five or fewer cows in the household. If there were more than five cows in a household, we randomly selected only five and measured.

Household incomes in 2016 were compared with household incomes in 2003. The income data for 2003 included data for 17 households (five Hmong and 12 Khmu) (LSUAFRP 2003). One of the authors of the current study (K.P.) was also involved in the LSUAFRP project and was tasked with collecting data in the

village. The data collection in 2003 and 2016 were done by the correspondent author using the same method.

In addition, we classified the cattle grazing systems prevalent in the village using three major components based on the previous studies conducted in Lao PDR (Table 3).

Free-range cattle are free-grazing and this was the most popular feeding type (Table 3). Previously, land-sharing has been relatively common between groups of villagers within a village, and between villages in a region (Pravongviengkham 1998; Takai and Sibounheuang 2010). More recently, some land-owning households have taken action to exclude other households from using their land, e.g. by fencing pasture land to exclude free-ranging cattle (Phonvisay *et al.* 2016). Additionally, villagers have enclosed land in order to: grow forage (Phonvisay *et al.* 2016); prevent cattle from feeding on cash crops (Takai and Sibounheuang 2010); and prevent thefts and wild-animal attacks on livestock (Pravongviengkham 1998; Nakatsuji 2010). Overall, we classified 18 different systems in Laos based on the feeding methods, land-use population unit, and land type, nine of which were novel (Table 3). These systems were then considered in the context of seasonality between the wet and dry seasons.

To test the influence of grazing systems on cattle productivity, we used analysis of variance (ANOVA) and a generalised linear model with *t*-tests. Heart girth is a predictor of liveweight and was, therefore, used as an index of cattle bodyweight (MacDonald *et al.* 2008; Lukuyu *et al.* 2016). All data were analysed in R 3.4.0

Results

Changes to household income structure

Compared with 2003, the total income of villagers was over two times greater in 2015 (Fig. 3), showing that the villagers are increasingly taking part in the market economy. This rise marks a shift from their engagement in diverse activities for livelihood to a greater reliance on cash-earning, specifically on cattle production and off-farm jobs.

An income disparity grew between the Hmong and Khmu groups during this period. By 2015, Hmong households earned on average 1.8 times more than Khmu households, largely because Hmong households increased cattle production. The Khmu men worked more often as agricultural labourers and construction site workers in urban areas. Most Khmu households did not keep cattle. The income from cash crops did not change much during this period.

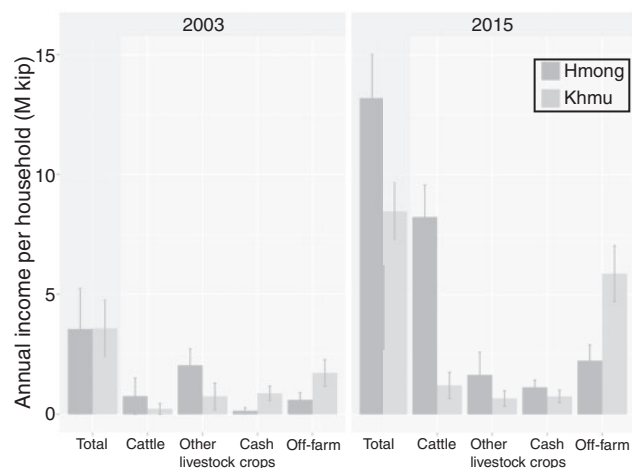
Differences in land use and number of cattle

The overall landholding size was significantly larger and land use more diversified in the Hmong households than in the Khmu households (Table 4). The average size of the land owned by the Hmong households (6.8 ha) was 2.8 times larger than that owned by the Khmu households (2.4 ha). Hmong households also held more land plots (on average 3.9 plots) than the Khmu households (on average 1.6 plots) (Table 5). The land area used for pasture, rubber, and teak plantations was significantly greater for Hmong households, but area used for swidden-farming was not significantly different between Hmong and Khmu households (Table 4). The Hmong households invested in a wider range of

Table 3. Published data on the cattle grazing systems in Lao PDR

N/A, no published data available

Classification	Feeding method	Land-use population unit	Land type	References
LA01	Free-ranging	Region, village, or within-village group	Fallow and natural vegetation	Pravongviengkham (1998); Takai and Sibounheuang (2010); Shirai and Yokoyama (2014); Phonvisay <i>et al.</i> (2016)
LA02	Free-ranging	Region, village, or within-village group	Fenced-fallow and natural vegetation	Pravongviengkham (1998); Nakatsuji (2010); Phonvisay <i>et al.</i> (2016)
LA03	Free-ranging	Region, village, or within-village group	Fenced pasture	N/A
LA04	Free-ranging	Household	Fallow and natural vegetation	N/A
LA05	Free-ranging	Household	Fenced-fallow and natural vegetation	Pravongviengkham (1998); Phonvisay <i>et al.</i> (2016)
LA06	Free-ranging	Household	Fenced pasture	N/A
LA07	Cut-and-carry	Region, village, or within-village group	Fallow and natural vegetation	Pravongviengkham (1998)
LA08	Cut-and-carry	Region, village, or within-village group	Fenced-fallow and natural vegetation	Pravongviengkham (1998)
LA09	Cut-and-carry	Region, village, or within-village group	Fenced-pasture	Phonvisay <i>et al.</i> (2016)
LA10	Cut-and-carry	Household	Fallow and natural vegetation	N/A
LA11	Cut-and-carry	Household	Fenced-fallow and natural vegetation	Pravongviengkham (1998)
LA12	Cut-and-carry	Household	Fenced pasture	Millar and Photakoun (2008); Phonvisay <i>et al.</i> (2016)
LA13	Herding	Region, village, or within-village group	Fallow and natural vegetation	Pravongviengkham (1998); Takai and Sibounheuang (2010); Phonvisay <i>et al.</i> (2016)
LA14	Herding	Region, village, or within-village group	Fenced-fallow and natural vegetation	N/A
LA15	Herding	Region, village, or within-village group	Fenced-pasture	N/A
LA16	Herding	Household	Fallow and natural vegetation	N/A
LA17	Herding	Household	Fenced-fallow and natural vegetation	N/A
LA18	Herding	Household	Fenced pasture	N/A

**Fig. 3.** Changes in the income structures of the Hmong and Khmu households between 2003 (LSUAFRP 2003) and 2015.

crops, whereas Khmu focussed almost entirely on swidden-farming (86% vs 42% for Hmong). In addition, over half of the Hmong households grew forage in at least one field, using 37% of

Table 4. Mean ($\pm$ s.e.) number of the Hmong and Khmu households engaging in various land uses and cattle production

Within columns, means followed by different letters indicate significant differences (95% confidence level)

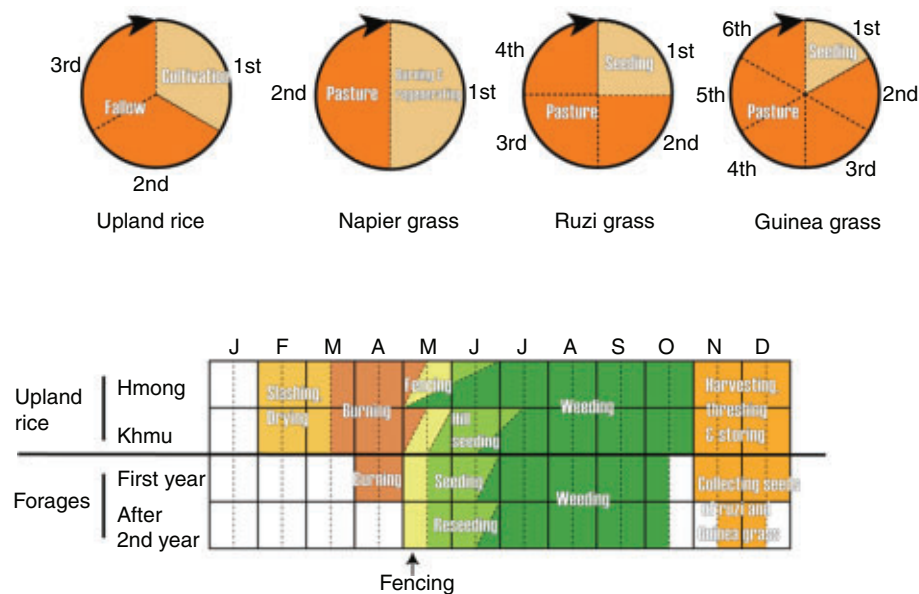
	Hmong	Khmu
<i>Land use</i>		
Number of households	52	40
Landholding size (ha)		
Total	6.8 $\pm$ 0.6a	2.4 $\pm$ 0.4b
Swidden	2.4 $\pm$ 0.3	2.0 $\pm$ 0.4
Pasture	3.1 $\pm$ 0.4a	0.2 $\pm$ 0.1b
Rubber	1.0 $\pm$ 0.2a	0.1 $\pm$ 0.0b
Teak	0.2 $\pm$ 0.1a	0.1 $\pm$ 0.0b
Other	0.0 $\pm$ 0.0	0.1 $\pm$ 0.0
<i>Cattle raising</i>		
Number of households	50	8
Herd size	8.1 $\pm$ 0.1	5.8 $\pm$ 2.0

their land on average, whereas most Khmu households did not grow forage at all (Table 5).

Most Hmong households (79%) raised cattle significantly more than the 20% of Khmu households that raised cattle

Table 5. Amount of arable land and its ratio to the number of households and the total amount of land, separated by ethnic group

	Total amount of land (plots)	% land/household (<i>N</i> = 52)	% of each type per total land				
			Land	Swidden	Forage	Rubber	Teak
<i>Hmong</i>							
Inheritance	9	0.2	4.4	2.9	1.0	0.5	0.0
Allocation	88	1.7	43.1	13.2	21.6	8.3	0.0
Purchased at or before migration	76	1.5	37.3	25.0	0.0	10.8	1.5
Purchased after migration	30	0.6	14.7	0.0	14.7	0.0	0.0
Rent	1	0.0	0.5	0.5	0.0	0.0	0.0
Total	204	3.9	100.0	41.7	37.3	19.6	1.5
<i>Khmu</i>							
Inheritance	1	0.0	1.6	0.0	1.6	0.	0.0
Allocation	36	0.9	56.3	48.4	1.6	1.6	4.7
Purchased at or before migration	24	0.6	37.5	34.4	0.0	3.1	0.0
Purchased after migration	1	0.0	1.6	0.0	1.6	0.0	0.0
Rent	2	0.1	3.1	3.1	0.0	0.0	0.0
Total	64	1.6	100.0	85.9	4.7	4.7	4.7

**Fig. 4.** Yearly cropping schedules (top) and cropping calendars (bottom) of upland rice and forage crops.

(Table 4). Among the households that raised cattle, the herd size difference was not significant.

Both ethnic groups primarily acquired land through the village authority and purchases from other households at or before migration (Table 5). In addition, the Hmong households made post-migration land purchases for forage cultivation.

Cropping schedules of upland rice and forage crops

Upland rice was grown through swidden farming with a two-year fallow period, and with households normally owning three plots of upland rice fields and farmers rotating rice cultivation among the three plots (Fig. 4). Both Hmong and Khmu households conducted land preparation and seeding before the wet season

and harvested after the wet season. Additionally, both groups fenced fields to protect upland rice from cattle grazing and destructive wildlife such as boars. Overall, the two ethnicities did not differ in their cropping schedules. During the fallow period, farmers did not weed the fields or apply fertilizer; cattle were allowed to graze freely in the fallow fields.

As of 2016, only Napier grass (*Pennisetum purpureum*), Ruzi grass (*Brachiaria ruziziensis*) and Guinea grass (*Panicum maximum*) were being grown as forage crops in the village. The Hmong households indicated that they had grown only Napier grass as a forage crop in their natal villages and were introduced to the other two forage crops through LSUAFRP.

Forage crops differed significantly in the years of pasture use, but not in the cropping calendars (Fig. 4). During the first year, all

three forage crops were seeded after the commencement of the wet season, weeded for a few weeks, and grown to grazing-suitable pasture by November. The Ruzi and Guinea grasses can be used as pastures for three to five years (if properly managed with fence repair, reseeding, and weeding) after which farmers have to clean and regrow them. Because the Napier grass pastures must be burned for regeneration every two years, farmers need to replant Napier grass in areas where the Napier grass has died out. Although the Napier grass appeared to require more labour, villagers were accustomed to grow the Napier grass and found its management easy. The labour competition between upland rice and forage cultivation was higher during the wet season than during the dry season.

Types of cattle grazing systems

Five cattle grazing systems (Table 3) were identified during the last decade: system A, free-ranging in fallow and natural vegetation (LA01) in both seasons; system B, wet-season free-ranging in fenced-fallow (LA02) + dry-season LA01; system C, wet-season rotational grazing in fenced pasture + dry-season LA01; system D, rotational grazing in fenced pasture in both seasons; and system E, cut-and-carry (LA12) in both seasons (Fig. 5). System E was the stall-feeding method introduced by LSUAFRP. As of 2016, systems B, C, and D were still active. Of the feeding types reported in previous studies (Table 3), only free-range grazing was still in use. In addition, system C (rotational grazing) was becoming predominant. Some villagers

still use the LSUAFRP-introduced communal land for cattle grazing.

The national road to Luang Prabang separates Pong Pao into the north and south portions. The Hmong group uses the land to the north of the road, whereas the Khmu group uses the land to the south of the road. The group-managed fenced pastures were present in the Hmong natal villages (e.g. Pha Toop, Phou Soong Noy and Phou Ja Norm), located within a radius of ~4 km from Pong Pao. Only the households that originated from these villages were allowed to use the fenced pastures. Although we did not observe a clear relationship between household landholdings and forage crops, the Napier grass was more likely to be grown in the group-managed fenced pastures.

Previous studies in Laos did not mention rotational grazing. In the present study, we found that the Hmong group rotated their cattle among the household-managed and group-managed pastures during the wet season (system C) or across both the wet and dry seasons (system D). Villagers reported moving cattle to another pasture when the forage in one pasture had been completely grazed; the pasture fields are then fenced, and the forage regrown.

Although cattle were vaccinated in all grazing systems, villagers employing system B vaccinated only the cattle that showed signs of infection. More attention was paid to cattle health in systems C and D. According to the respondents, system D was the most labour-intensive (based on forage crop cultivation and yearly cattle grazing schedule), followed by systems C and B. The cattle numbers in each of the grazing systems B, C and D were 48, 224, and 181 respectively.

Most Hmong households employed systems C and D (Table 6). Only 15% of the total sampled households raised cattle using system B, and the majority of these were Khmu. The cattle density differed significantly between systems C and D ($P < 0.05$), but not between systems B and D. The significant difference was attributable to the increased amount of cattle raised under system C, despite a greater ratio of pasture size to the total landholding size in system D. However, the pasture size and number did not significantly differ between systems C and D. Furthermore, three systems (B, C and D) had similar herd size and cattle per labourer (Table 6). We also observed that the group-managed fenced pastures in natal villages of Hmong were able to considerably improve the rotational grazing capability. In systems C and D, even households with no pastures or only a single pasture could rotate their cattle among these group-managed pastures.

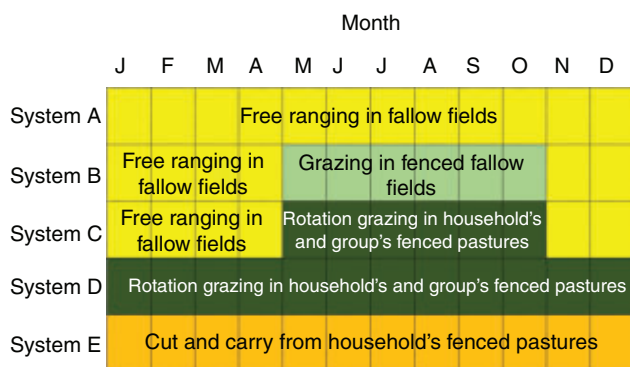


Fig. 5. Types of cattle grazing systems in use at Pong Pao.

Table 6. Variation in the land-use characteristics of the Hmong and Khmu households across the cattle grazing systems

Within rows, means ($\pm$ s.e.) followed by different letters indicates significant difference (95% confidence level). System: B, free-ranging at fenced-fallow (LA02) in wet-season + free-ranging at fallow and natural vegetation (LA01) in dry-season; C, rotational grazing at fenced pasture in wet-season + LA01 in dry-season; D, rotational grazing at fenced pasture in both seasons

System	Number of households		Herd size	Number of labourers	Total land size (ha)	Swidden (ha)	Number of pastures	Pasture size (ha)	Cattle per labourer	Cattle density (herd size/pasture size)	Pasture size/total land size
	Hmong	Khmu									
B	3	7	4.8 ± 1.6	2.8 ± 0.3	$1.9 \pm 0.4a$	1.7 ± 0.4	0a	0a	1.7 ± 0.5	2.5^A	–
C	27	0	8.3 ± 1.2	3.5 ± 0.3	$6.9 \pm 0.8b$	2.4 ± 0.4	$1.5 \pm 0.2b$	$3.0 \pm 0.6b$	2.6 ± 0.4	$3.8 \pm 0.4a$	$0.4 \pm 0.0a$
D	20	1	8.6 ± 1.5	3.6 ± 0.8	$7.5 \pm 1.1b$	2.4 ± 0.4	$1.7 \pm 0.2b$	$4.2 \pm 0.6b$	2.6 ± 0.4	$2.5 \pm 0.4b$	$0.6 \pm 0.1b$

^AEstimate based on size of fenced fallow fields in the wet season (10 ha).

Changes in cattle grazing systems

The Hmong and Khmu groups differed significantly in the changes made to their cattle grazing systems. In 2000, most households either raised cattle using system A or had no cattle, regardless of their ethnicities (Fig. 6). Since 2004, the Hmong households increasingly began to use systems B, C, D and E; there was also a decrease in the use of system A and in the number of households not raising cattle. By 2016, systems A, B and E were used considerably less than systems C and D. Many households stopped using system E because it was easier to graze in a fenced area than use the cut-and-carry (system E). Another reason why respondents felt that the extra effort involved in cut-and-carry was not justified, was the difference in price when the cattle were sold. In contrast to the Hmong households, the proportion of no-cattle households among the Khmu households remained consistent during 2000–2016. However, the use of system A declined among the Khmu households from 2006 until it was completely replaced with system B or C by 2016. The reason for the decline in use of system A was because the land area became more limited as the area occupied by rubber and other cash crops increased in the village. Therefore, villagers assigned and fenced-fallow and fenced pastured for cattle grazing. Of the studied households, two households stopped cattle production entirely because all cattle had died or were sold.

In summary, the Hmong households drastically changed their production strategy over the 17-year analysis period, experimenting with several systems before selecting C or D. Furthermore, some households with no cattle also participated in these two systems because they used to have cattle before 2016. In contrast, the Khmu households showed an overall simpler trend of shifting from system A to system B (Fig. 6) because Khmu households engaged in swidden-farming and have no forage fields.

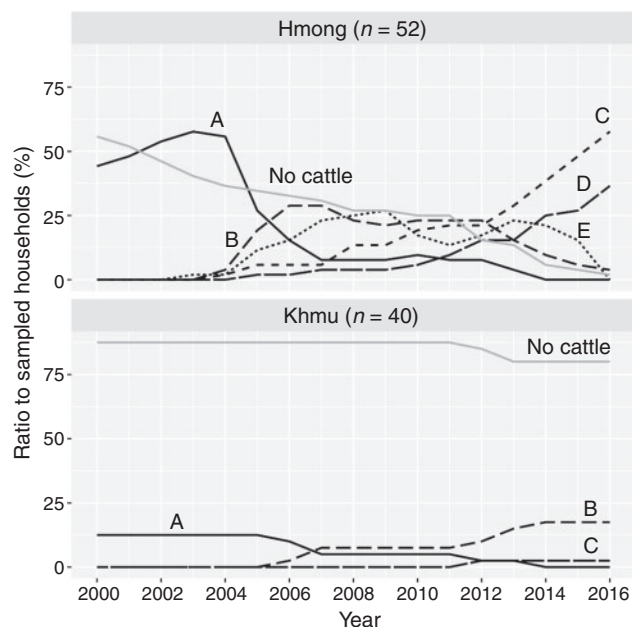


Fig. 6. Changes in the use ratio of cattle grazing systems (described in Fig. 5) among the Hmong and Khmu groups.

Differences in cattle growth among grazing systems

As expected, there was a difference in the growth rate of male and female cattle, with males growing faster than females by age four (Fig. 7). Beginning at age three, female heart girth remained consistent at ~1.4 m as they reached maturity. Sex differences among older cattle could not be compared because the village had no males older than five years; the bulls were typically sold when they were approximately four years old, whereas the cows were kept until they were 12 years old.

Heart girth among cattle aged one to four was significantly related to their age, sex, and the ethnicity of the households that owned the cattle, but not to the grazing system or socioeconomic variables, implying the rejection of our hypothesis, which proposed that different grazing systems may lead to differences in cattle productivity (Table 7). The Khmu households tended to have cattle with heart girths larger than those owned by the Hmong households. Although the pasture size had no significant effect on cattle growth, the positive effect of number of pasture plots trended towards significance ($P = 0.0801$); this may be because Khmu cattle were fewer in number and they were free grazing in the fallow-fenced area, where natural grass was grown, whereas Hmong households have more cattle and grazed in assigned and fenced areas.

Discussion

Responses to land constraints under rising beef prices

The Hmong and Khmu groups differed noticeably in their responses to rising beef prices, which increased from 34 139 Lao kip/kg in January 2010 to 66 256 Lao kip/kg in January 2015 (Lao Statistics Bureau 2011, 2016). The Hmong households diversified their livelihood portfolios, building on their cattle production and other forms of commercial farming (e.g. rubber plantations) to supplement swidden farming of upland rice.

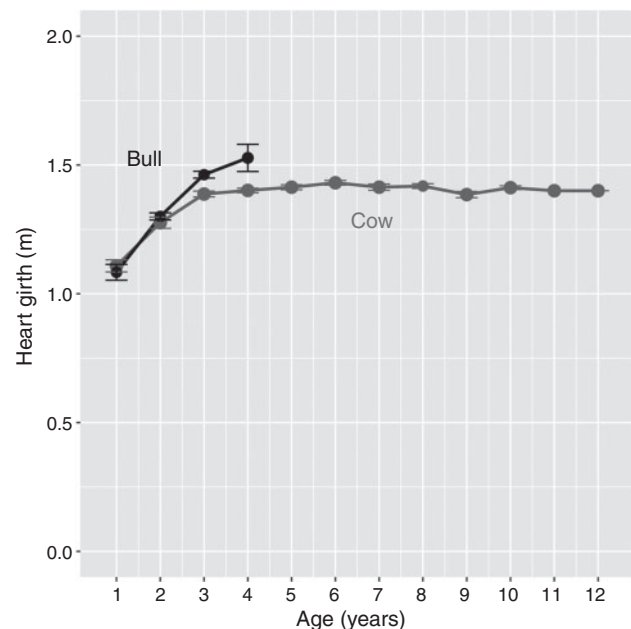


Fig. 7. Growth of male and female cattle as indicated by their heart girths.

Table 7. Results of generalised linear model examining variables affecting cattle heart girth as a proxy for growth ($n = 138$)

	Estimate	Standard error	<i>t</i> -value	Pr ($> t $)
(Intercept)	86.28404	6.11553	14.109	$<2.0 \times 10^{16}$
<i>Variables related to cattle heart girth</i>				
Cattle age	1.05747	0.06746	15.676	$<2.0 \times 10^{16}$
Female		<i>–Reference category for the male–</i>		
Male	4.9929	1.9346	2.581	0.0110
<i>Grazing system variables</i>				
System B		<i>–Reference category for the system C and D–</i>		
System C	–0.45421	3.99089	–0.114	0.9096
System D	3.06883	3.68457	0.833	0.4065
Cattle density	0.70163	0.57553	1.219	0.2251
<i>Socioeconomic variables</i>				
Hmong		<i>–Reference category for the Khmu–</i>		
Khmu	10.77809	4.57176	2.358	0.0199
Labour force	0.91198	0.66253	1.377	0.1711
Number of pastures	1.57136	0.89052	1.765	0.0801
Pasture size	0.18158	0.63376	0.287	0.7750

In contrast, the Khmu households focussed on subsistence-oriented swidden farming and off-farm work, without increasing cattle production. In the villages of origin, the Khmu households generally had fewer assets and earned less than Hmong households.

In conjunction with their diversified portfolio, the Hmong households were more likely to purchase extra land for forage cultivation. The households of both ethnicities received identical-sized plots upon arrival in the village, but the Hmong group purchased land from the Khmu group after immigration. As a result, the landholding area was significantly larger among the Hmong households than the Khmu.

However, neither ethnic group possess enough land for maintaining their livelihood, as the village authority limits the total area that can be officially allocated to them. Villagers stated in their interviews that the field rotation for upland rice cultivation occurs in a three-year cycle (two-year fallow period followed by rice cultivation). However, neither the Hmong nor the Khmu households had sufficient land (the Hmong had an average of 6.8 ha of land in an average of 3.9 plots; the Khmu had an average of 2.4 ha of land in an average of 1.6 plots) for swidden farming, unless the communal or unallocated land is also used for cattle grazing. In addition, the village does not contain enough pastures for effective rotational cattle grazing; for instance, many Hmong households own less than two plots for forage cultivation in Pong Pao and must supplement with communal lands in their natal villages where they cultivated forage. A clear negative consequence of this situation is the expansion to unauthorised land, such as conservation forests, widely observed in upland villages in northern Laos (Pravongviengkham 2004).

The distinctly different responses of the Hmong and Khmu groups were more attributable to their livelihood history than to ethnicity. The Khmu households did not have communal lands for rotational grazing or saved capital from lucrative agricultural businesses (e.g. opium cultivation and cattle herding reported in LSUAFRP 2003), as the Hmong households did in their natal villages. Thus, the Khmu have few options besides selling their land and focusing on off-farm work to earn their livelihoods.

Changes to cattle grazing systems

The principal driving forces of changes in crop–livestock systems are natural resources, population pressure, urbanisation, and market opportunities. These driving forces have also been reported in studies in West Africa (Fernández-Rivera *et al.* 2004). For example, in the Harar Highlands of Ethiopia, as more land is used to grow cash crops, farmers lease out or sell animals instead of overstocking animals on the smaller areas of land available for grazing (Kassa *et al.* 2002). In Laos, the diminishing available land and raising opportunity to export beef to Vietnam and China are likely a major impetus for the observed changes in cattle grazing systems. As the population of Pong Pao rose sharply during 2000–2004, a corresponding limitation of the natural grazing area negatively affected rice production as free-ranging livestock use the upland fields as grazing area (Takai and Sibounheuang 2010). As confining the cattle was the easiest way of preventing crop damage, the Hmong households drastically decreased their use of free-range grazing beginning in 2004 and switching to the fenced-in fallow fields during the wet season. Further, to mitigate over-grazing under confinement, the Hmong farmers also included forage crops and rotational grazing. The latter method reducing the grazing pressure and necessary pasture size compared with continuous grazing (Hart *et al.* 1993). However, the pastures included in rotational grazing were located in the Hmong natal villages, and the long travel distance and extra effort could outweigh any positive effects on weight gain for the cattle (Hart *et al.* 1993).

The swidden farming system (in which the land is ‘slashed and burned’ and then primarily planted with rice followed by upland rice fallow) provides a significant grazing area during dry season, which allows the villagers to feed cattle throughout the year. During the dry season, the free-range grazing resulted in a higher number of cattle, whereas the rotational grazing increased the ratio of the pasture size to the total landholding size. The two systems did not differ in pasture size or number. These results suggest that fallow fields hold larger numbers of cattle. Contrary to expectation (e.g. Horne 1998), growing forage in the dry season did not increase the herd size unless farmers made hay

or silage. Indeed, compared with fallow vegetation, the forage crops improved fodder quality as well as quantity in the wet season, but did not improve fodder uptake during the dry season. This finding was a part of the reason why the cut-and-carry system had fallen out of favour by 2016, and had largely been replaced with rotational grazing. Another factor that contributed to this change was labour intensity. Villagers found that the cut-and-carry system required more labour than free grazing. This contradicts previous suggestions that the cut-and-carry system was relatively less labour-intensive for livestock (such as pigs, cattle and goats) that needed supplementary fodder in the dry season especially in lowland villages (Millar and Photakoun 2008; Stür *et al.* 2013).

Effects of forage crops and rotational grazing on cattle productivity

Differences in grazing systems (e.g. pasture size and number) did not affect the cattle body size, with only age and sex being significant factors. This result implies that the pastures and fallow vegetation are equally effective in maintaining cattle; however, there is potential to increase the cattle performance if the cattle are properly fed, e.g. by intensive fattening. Therefore, forage crops should contribute to maintaining, and possibly increasing, cattle body size, even if the fallow grazing area decreases. In addition, the lack of a relationship between pasture plot number and body size could be ascribed to the intervening effects from the increased travel distance to pastures and water (Hart *et al.* 1993). Monitoring cattle grazing behaviour via GPS might, therefore, contribute to improving grazing systems (Turner *et al.* 2000; Shirai and Yokoyama 2014).

Cattle, particularly bulls, in the study village have the potential for weight increase. The domestic yellow bulls and cows in Laos can weigh up to 600 and 400 kg respectively (Wilson 2007). Further, the liveweight of a bull at age four is ~200 kg, whereas a mature cow weighs only 180 kg (MacDonald *et al.* 2008). The use of the cut-and-carry fattening methods also warrant more consideration in terms of increasing cattle productivity (Nampanya *et al.* 2014); in northern Vietnam, the same breed of cattle supplemented with cut-and-carry forage grew to 220–230 kg at the age of four years (Huyen *et al.* 2011). However, market push, government support and a cost–benefit analysis that considers villager descriptions of increased labour must be performed before expending more effort on encouraging the cut-and-carry system or maintaining free-grazing (Phonvisay 2013).

Overall, the swidden farming-based grazing resulted in the highest cattle holding, an outcome that seems linked to the increased labour intensity of maintaining rotational grazing all year long compared with grazing on fallow fields with larger areas. Thus, even if the rising beef prices appear to offset productivity decreases, increased labour requirements and decreased soil fertility were observed under rotational grazing because this system in the fenced pasture plots puts more pressure on soil as there is a shorter duration for soil nutrient recovery (Roder *et al.* 1995). However, if rotational grazing is allowed in assigned areas, the soil would receive nutrients in the form of manure. This might diminish the actual economic return from cattle raising efforts because the poor soil leads to relatively less

forage biomass, which in turn affects cattle performance. Moreover, the labour shortages per household do not seem to be an issue in Pong Pao, in contrast with other studies concerning cattle production in northern Vietnam (Huyen *et al.* 2010). However, more research on the exact time allocation of household labour on cattle production would provide further insight into the division of labour and existence of potential shortages.

Changing crop–livestock systems

The different forms of crop–livestock systems are decreasing or increasing in popularity in the study village as land quotas, an increasing population, and changing economics force households to alter their land-allocation strategies and use unallocated lands. In particular, the introduction of cash crops has reduced the land available for subsistence-based swidden farming of rice and cattle grazing. Of the five systems developed to use the remaining land, the systems that incorporate forage crops (i.e. system C) have become more popular because rotational grazing is employed in forage pastures only during the wet season, with the supplementation of free-range grazing on fallow vegetation in the post-harvest dry season. This method successfully maintains both upland rice and cattle production, while increasing the cattle holding capacity of the village. In contrast, the systems dependent on grazing in fenced fields (systems B and D) are becoming less popular. This is probably due to increasing tensions between rice and cattle production during the wet season. Specifically, the emphasis of system B on grazing in fallow fields limits cattle production, as the land is already being used for rice cultivation. Likewise, the focus of system D on the year-long pasture grazing prevents that land from being converted to rice fields. As seen in the Khmu households, the land constraints and rising cattle prices can limit cattle production among smallholders, whereas the upland rice production excludes the land from being used for cattle grazing and vice versa. In systems where the cattle graze only on fallow vegetation, a shortened fallow period that degrades the fallow fields also limits cattle productivity, increasing the difficulty of maintaining such systems.

Crop–livestock systems have long provided food security and have a continued potential to mitigate the adverse effects of the changing market conditions in northern Laos (Nie *et al.* 2016). Declines in such systems to simply favour intensifying cattle production could increase smallholder vulnerability to a fluctuating market. Furthermore, animal wastes from intensive industrial livestock degrade environment quality (Naylor *et al.* 2005). Thus, future studies should expand their focus from profitability to include the investigations of food security and household safety nets. In addition, the efficiency of resource use (e.g. circulation of raw materials) across various crop–livestock systems should be compared for a better evaluation of livelihood sustainability.

Conclusions

The traditional free-range, swidden-based grazing system in Pong Pao village of northern Laos has evolved under increasing pressure from land constraints and changing market economy. The three systems that have emerged include: (1) grazing fenced

fallow vegetation during the wet season; (2) rotational grazing in pastures during the wet season; and (3) rotational grazing in pastures during both dry and wet seasons. None of the systems increased cattle body size but the system that integrated pastures and swidden-farming successfully increased the grazing capacity, and balancing crop and cattle production in the context of land constraints. Therefore, the rising financial costs of cattle production prevented households that did not have savings from raising cattle, leading to a wide disparity in annual income and landholding size.

Conflicts of interest

The authors declare no conflicts of interest.

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