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When money meets tradition: How new cash incomes could be risky for a vulnerable ecosystem

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A B S T R A C T

Economic incentives to simultaneously address poverty and biodiversity loss may fail if they do not align with local values or norms. Grazing livestock across the Tibetan Plateau's vast but fragile grasslands is often characterized as the area's primary driver of habitat degradation. China's grassland restoration policy provides eco-compensation subsidies for herders, with the assumption that providing extra cash income will help alleviating grazing pressure. We investigated potential impacts of this supplementary income, in combination with caterpillar fungus, a major local cash income source, on the pastoral livelihood on the Tibetan Plateau. Through field livestock census in seven communities and household livelihood interviews with 153 households we found that at both household and valley levels, eco-compensation didn't have the intended effect of reducing grazing pressure, while caterpillar fungus income has significant positive relationships on grazing intensity. Meanwhile, we found significant decrease of above-ground plant biomass after policy implementation was linked with low-elevation pastures with most intensive grazing, which indicated a negative impact of grazing on grassland condition at our study sites. Further, based on herdsmen's perceptions on different cash income sources we suspected those non-pastoral incomes might have even subsidized pastoralism. We suggested future economic incentives related to grassland restoration should be more targeted towards villages with low cash income and overgrazed grasslands, with clearly stated responsibilities and obligations, instead of standardized cash payment.

1. Introduction

Economic incentives are recognized as a powerful ecological intervention in simultaneously alleviating poverty and protecting biodiversity (Adams et al., 2004; Martínez-Alier and Muradian, 2015; McShane and Wells, 2004; Rode et al., 2016). However these programs are often designed with simplistic, and sometimes erroneous, assumptions on the needs and rationales of the beneficiaries (Berkes, 2013; Wright et al., 2016), such as failing to take into account local values and customs that shape people's attitudes and motivations. In addition policies are rarely rigorously evaluated and there is a limited understanding of the effects of the policies on people's conservation behaviors (Chan et al., 2016; De Snoo et al., 2013).

China suffered accelerated ecosystem degradation at the early stage (Year 1978–2000) of the nation's rapid economic development (Liu and Diamond, 2008, 2005; Matus et al., 2012). Subsequent environmental

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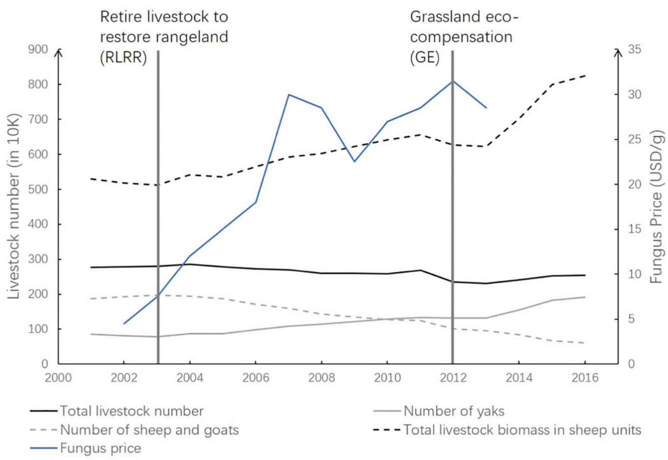

Fig. 1. Historical livestock numbers of the Yushu Prefecture, Qinghai Province from government statistics (data source: (Yushu Prefecture, 2001–2016)), fungus price change (data source: Weng, 2013) and key policy time. 1 yak = 5 sheep units, 1 horse = 6 sheep units (Miller, 2000). Horse number was too low thus was not displayed here.

disasters, such as the extensive floods and sandstorms in Beijing in 1998, prompted several large-scale ecological restoration programs that use economic incentives to solve environmental problems (Bennett, 2008; Liu et al., 2008; Xu et al., 2010). In 1999 and 2003, two major policies were enacted in China, the world's largest reforestation program "grain for green" on farmlands (Liu et al., 2008) and "retire livestock to restore rangeland" on rangelands (WDOSC et al., 2003). The designed rangeland policy included a grazing ban, relocation of herders out of severely degraded rangelands (so-called "ecological immigrants"), and a reduction of livestock numbers to a predicted carrying capacity (forage-livestock balance) on moderately degraded rangelands.

Accordingly, the government provided subsidies in the form of fodder and cash to livestock herders in order to compensate their predicted livelihood loss (Ministry of Agriculture, 2012). In 2012, a follow-up program "grassland eco-compensation" was initiated with the central government drastically increasing subsidies for herders and investing 15.975 billion CNY annually (Ministry of Agriculture and Ministry of Finance, 2011), nearly the amount invested in the previous 8 years combined. The designed standard was 1.5 CNY (about 0.23 USD) per mu (1 ha = 15 mu) for "forage-livestock balance" area and 6 CNY (about 0.95 USD) per mu for the year-round "grazing-ban" area.

After high input of grassland eco-compensation in an area as big as the United Kingdom (267,000 km^2), the outcome was not always in line with the original intention of the policy makers – to reduce the overall grazing intensity. For instance, the official livestock number reported by Yushu Prefecture on the Tibetan Plateau showed a decrease in total livestock number, but an increase in livestock biomass represented by sheep equivalent unit (Miller, 2000), mainly due to the change of livestock composition from sheep to yaks (Fig. 1). Note that government statistics tend to underestimate the real livestock number as herders report less to meet government's expectations (Sulek, 2011; Wang et al., 2016). Previous research (reviewed by Gongbuzeren, 2015; Li and Li, 2016) on the ecological effects of China's grassland restoration policy was based on either grassland remote sensing data, where climatic vs policy impacts could not be separated; or on fine-scale grassland quadrat measurements, which could not assess impacts at a scale appropriate to evaluate policy implementation.

On the Tibetan Plateau, one of largest pastoral regions of China, at around the same time that these policy changes were taking place, a market for caterpillar fungus (*Ophiocordyceps sinensis*) began to boom. The caterpillar fungus parasitizes larvae of ghost moths *Thitarodes* spp.

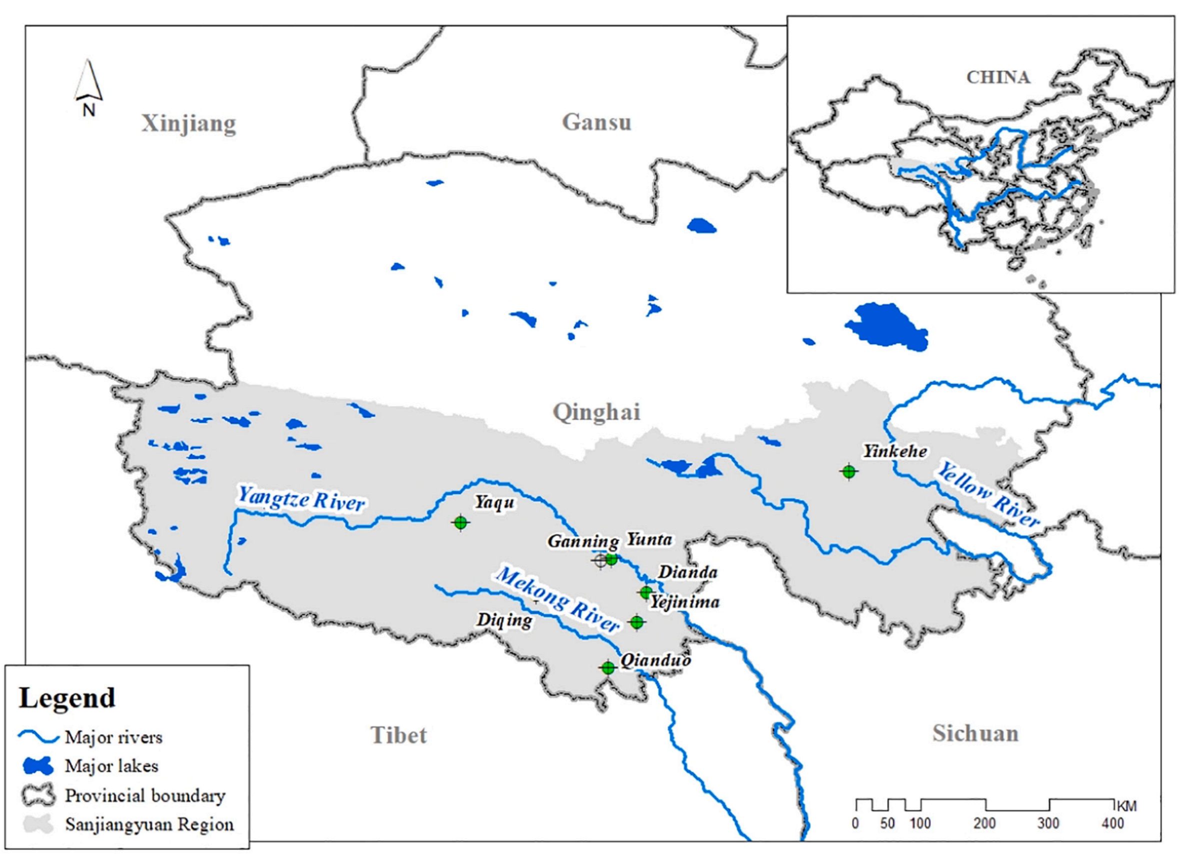

Fig. 2. The location of seven selected communities (solid circle) together with Ganning community (open circle) which replaced Yinkehe in livelihood interviews.

and produces a fruiting body, which has been used in Chinese medicine for at least 2000 years as an affordable tonic. However, the price of caterpillar fungus increased by 900% in international markets from 1997 to 2008 (Winkler, 2009) and fetched up to 200 CNY (30 USD) per gram in 2017 (Cunningham and Long, 2019). The pursuit of wealth from this lucrative profit margin resulted in a fungus "gold-rush" that contributes 40%–90% of cash income to the local household livelihoods, and thus replaced pastoral products as the most important source of cash income (Shrestha and Bawa, 2014; Sulek, 2011; Weckerle et al., 2010). In spite of its prominence in impacting local livelihoods, the effect of caterpillar fungus income on livestock stocking rates is undervalued in lines of inquiry at both academic and political contexts.

In this context, dissolving the possible relationships of real grazing pressure based on field census (but not official data), with these economic incentives from both policy and market, on a scale pertinent to land-use policy-making, are highly salient questions. The results of this study can increase our understanding of perverse subsidy effects more broadly. Here, we attempt to address these knowledge gaps and test the assumption that supplementary incomes (whether from policy incentives or fungus markets) will help reduce grassland pressure.

Given the lack of reliable time-series livestock number data based on field census, we applied a space-for-time method (Pickett, 1989) by choosing seven communities (natural villages) on the Tibetan Plateau to represent a gradient of different grazing intensity. Firstly, we aimed to assess the impact of non-pastoral income on grazing intensity at two scales, landscape and household. The landscape scale links to inferences on meaningful ecological conditions of grasslands in studied communities. Our household scale provides inference into the livelihood decision of each household on traditional pastoralism. Secondly, to link land-use intensity and potential impacts of overgrazing to grassland condition, we investigated the pattern of grassland above-ground biomass changes in the seven villages indicated via Enhanced Vegetation Index (EVI) from 2000 to 2017. Finally, we provided possible explanations on how local religion and economic values might mediate the impact, and provide suggestions on policy design and implementation.

2. Materials and methods

2.1. Study area

The Sanjiangyuan Region (SR) is located in the northeastern part of the Tibetan Plateau, with an average elevation of 4200 m a.s.l. The vegetation in the area is mostly alpine meadows and steppes, with large rivers and wetlands, and scattered montane forests (Editorial Commitee of Ecological Environment of Sanjiangyuan Nature Reserve, 2002). The human population was 856,031 in 2014, 70% of whom were Tibetan pastoralists (Qinghai Province Statistics Bureau, 2015). The livestock raised here are mainly yaks and sheep. Protected by its harsh environment and remoteness, SR still harbors some of the last intact wilderness and wildlife assemblages in China, including such notable mega-fauna as the snow leopard (*Panthera uncia)*, common leopard (*Panthera pardus*), Tibetan brown bear (*Ursus arctos)*, Tibetan antelope or chiru (*Pantholops hodgsonii)*, Tibetan wild ass or kiang (*Equus kiang)*, and wild yak (*Bos mutus)*. It has been reported that over 50% of the alpine grasslands in Sanjiangyuan were moderately or severely degraded (Liu et al., 2008) driven by complex interactions of anthropogenic and environmental factors such as land-use intensification (Li et al., 2017) and climate change (Lehnert et al., 2016).

We picked seven communities ("natural villages") from east to west across SR to represent a gradient of grazing intensity on the Plateau (Table S2). In a pre-survey in November 2011, based on official statistics of livestock number in 2011 collected by the Animal Husbandry Bureau of Department of Agriculture, Yushu and Golog Prefecture, we travelled from east to west of SR to search for suitable study sites. Considering the spatial pattern of grazing intensity in the SR (Fan et al., 2009), the seven communities were spaced >50 km from each other (Fig. 2), each covering 100–200 km^2, which inevitably introduced biophysical differences among them. We accounted for the possible confounding effects caused by these differences by including environmental covariates in the analysis, and confirming the lack of collinearity between these variables and non-pastoral incomes (see below).

2.2. Data collection

The study protocol obtained ethical approval from Peking University before data collection. Consent was obtained from township-level local government prior to entering each village. Informed verbal consent was obtained from all interviewees before interviews began. Interviewees were told that the interview would be anonymous, and they could withdraw at any point and choose not to answer any questions. The interviews were taken in the local Tibetan dialect with assistances of our Tibetan-Chinese interpreters. The interpreter translated the questions to the interviewees and then translated their answers to the interviewer. The interviewer took detailed notes related to the questions on printed questionnaires. We didn't use audio recording as it is more sensitive and might discourage the interviewees from speaking freely.

2.2.1. Household livestock census to estimate valley-level grazing intensity

We conducted a door-to-door household census within the seven communities in April 2014 to quantify year-round grazing intensity at the valley level. For each household we recorded the GPS location and interviewed a household respondent to collect information on the number of livestock owned for each livestock species. This information was crosschecked by the interviewer conducting livestock counts at dawn or dusk when livestock were inside or near the household enclosures. When counts from the two sources did not match, we would use the larger number, on the assumption that herders tended to underreport their herd size (Sulek, 2011; Wang et al., 2016).

Some households would use multiple valleys as seasonal pastures to safeguard enough forage for livestock in different seasons. We therefore also asked household respondents to report their pasture rotation time (in days) and the location of all their seasonal pastures. We defined grazing intensity for each valley based on Eq. 1 (following Bürgi et al., 2015; Li et al., 2017), in which HHS represents household herd size in sheep units, S the area of the valley, and T the proportion of days during a year the corresponding number of livestock spent inside the valley. Herd size was converted into standard sheep units (SU; 1 SU = 1 adult sheep, 1/0.9 goat, 1/5 yak, and 1/6 horse, following Miller, 2000).

$$\text{Grazing intensity} = \frac{\sum HHS \times T}{S} \quad (1)$$

2.2.2. Semi-structured livelihood interviews on sampled households

In a preliminary survey conducted in 2012, we interviewed 49 households from the seven communities. The interviews explored what herders considered were limiting factors for household herd size in order to inform the more in-depth 2014 questionnaire. We asked open-ended questions to understand the herders' view on this topic. Based on the answers we considered 4 potential factors that would affect each household's decision to keep livestock: pasture area, cash income, household labor force, and family size.

The semi-structured livelihood interviews conducted in November 2014 (see SI for detailed questions) contained both close and open-ended questions. The closed questions collected data on the relevant factors (pasture area, cash income, household labor force and family size) that could affect the decisions of a household pertaining to livestock keeping, while open-ended questions asked for interviewee's feeling and opinions on related questions. Qualitative data were analyzed using content analysis (Newing et al., 2011). Responses to open-ended questions were coded and the codes were grouped into categories.

We designed the sampling method according to the spatial distribution of households. We found households that spatially clustered together usually belong to the same large family. Considering the independence of each sample we picked one household from each cluster, while trying to spread the age coverage. In total we interviewed 153 Tibetan herder households (normally the head of the household) in the seven communities.

In relation to cash income, we asked about the income from three main categories 1) selling livestock or related products, 2) caterpillar fungus, 3) eco-compensation, and additional incomes from other sources including other types of governmental subsidy. For family size, we only counted the family members still living inside the village. For labor force, we asked about the total number of laborers inside a family and the number of labors taking care of the livestock. In the 1990s, each herder (including children) on the Tibetan Plateau was assigned a pasture safeguarded by a pasture contract (National People's Congress, 1985). People born after the 1990s have no contract but share their family's pasture. We therefore calculated pasture area of each interviewed household based on the recorded area on the pasture contract, together with the number of other households' livestock that shared the same contract.

2.2.3. Environmental covariates for valley-level grazing intensity

To test for determinants of valley-level grazing intensity, we collected potential covariates beside the non-pastoral incomes. We calculated community-level incomes by averaging the incomes from all interviewed households in 2014 inside a given community. We didn't calculate the valley-level incomes as some households would use multiple valleys as seasonal grazing pastures. We then considered eight confounding covariates potentially relevant to valley-level grazing intensity (Table S1).

Without the impact of non-pastoral incomes, we expected that the current grazing intensity would be an accumulative outcome from baseline intensity, previous years' forage, and climatic conditions. These covariates related to three valley-level factors: (1) topographical features, (2) forage condition averaged over the last 5 years (2011–2015), and (3) winter climatic conditions averaged over the last 5 years (2011–2015), which linked to extreme snow events; together with 4) baseline livestock density at the township level at the year 2011 (the year before the eco-compensation implementation). Data sources of these covariates were listed in Table S1.

2.3. Data analysis

2.3.1. Grazing intensity of each valley

We constructed generalized linear mixed models (GLMMs), using R package *lme4* to examine the impact of non-pastoral incomes on grazing intensity of each valley. We used a negative binomial GLMM to account for the over-dispersed data. We put non-pastoral incomes (fungus and eco-compensation) and the eight confounding variables into the model. Communities were set as the random effect to account for the clustered study design.

Prior to model construction we examined the collinearity of all candidate covariates using variance inflation factors (VIF). Slope was excluded with a VIF value >10. After covariate screening, we ranked all combinations of selected variables based on AICc value (AIC adjusted for small sample size) using R package *MuMIn*, and used a model-averaging approach to calculate the weight-average parameter values for all variables found in the top models, as indicated by delta AICc values ≤ 2 (Burnham and Anderson, 2004).

2.3.2. Household herd size

Out of the 153 semi-structural livelihood interviews, 90 provided effective samples that contain information on all relevant factors which we used in building the generalized linear model. We constructed GLMMs to examine the determinants of household herd size in total number of sheep units. We fit the data to a negative binomial distribution due to over-dispersion (Ver Hoef and Boveng, 2007). We put fungus income, eco-compensation income, pasture area, household labor force and family size into the model, together with community identity as the random effect to account for household clustering in the study. We followed the same model building procedure as in section 2.3.1 including testing for collinearity of the variables, model ranking and averaging. We didn't find any variables with VIF > 10. We used AIC value to determine our best-supported model (Burnham and Anderson, 2002).

2.3.3. Patterns of grassland above-ground biomass change

In order to trace the change of grassland biomass since the start of the policy change and sharp increase in fungus price (in 2000) within the seven villages, we extracted the growing season grassland enhanced vegetation index (EVI) data from the period 2000–2017. EVI is an 'optimized' vegetation index designed to enhance the vegetation signal from remote sensing images and showed a linear or exponential relationship with aboveground vegetation biomass in grasslands (Paruelo et al., 1997; Song et al., 2018; Tucker and Sellers, 1986; Yang et al., 2009). We acquired the EVI and the pixel reliability layer from the 16-day MODIS vegetation index composites with a 250 m spatial resolution (MODIS product: MOD13Q1 V006. Didan, 2015). We took the growing season EVI data, which is the average of EVI values every 16 days from June to September, and extracted only the EVI values of grasslands (excluded rock, bush, water body, ice and snow) with pixel reliability as "Good" or "Marginal data". We conducted vegetation index trend analysis by modeling the growing season EVI change of each **pixel** using linear regressions.

We then divided pixels into three grassland status classes: **unchanged**, **biomass decreasing** and **biomass increasing** by examining the slope and *p* values of the regression. Biomass decreasing pixels are those showing a significant negative slope with a p value <0.05. Biomass increasing pixels are those showing a significant positive slope with a p value <0.05. Unchanged pixels are those with non-significant changes ($p > 0.05$). We tested how topographic features (elevation, slope and aspect), baseline grassland condition (EVI in 2000), and current land-use intensity differed across the three grassland status classes. We used Wilcoxon-Rank-Sum tests to test the pairwise differences between the three grassland status classes.

3. Results

3.1. The local livelihood structure

Average household cash income was CNY 53871 (approximately USD 7862) per year, of which caterpillar fungus contributed the most (59.44%, CNY 32025, USD 4674). The fungus economy provided cash income in two ways: direct harvest, and indirectly through the access fee charged to outside collectors. Other income sources included pastoral income (sale of livestock and dairy products), eco-compensation subsidy, and other incomes (government subsidy for low-income families, stipend for village leaders provided by the government, and small businesses like grocery stores etc.) (Fig. 4a, Table S2).

3.2. The impact of non-pastoral income on household herd size and valley-level grazing intensity

From the preliminary survey we concluded that the four most important factors influencing the retention of livestock were: pasture area (mentioned by 32.7% of households), labor force (20.4%), extreme snow events (16.3%) and lack of funding (10.2%). Another 20.4% of interviewees claimed that their yaks were enough for family meat consumption thus there is no need to increase the herd size.

From the semi-structured interview data, the household herd size was shown to be significantly linked with family size and fungus income. The model selection process produced six top-ranked models (ΔAIC ≤ 2)

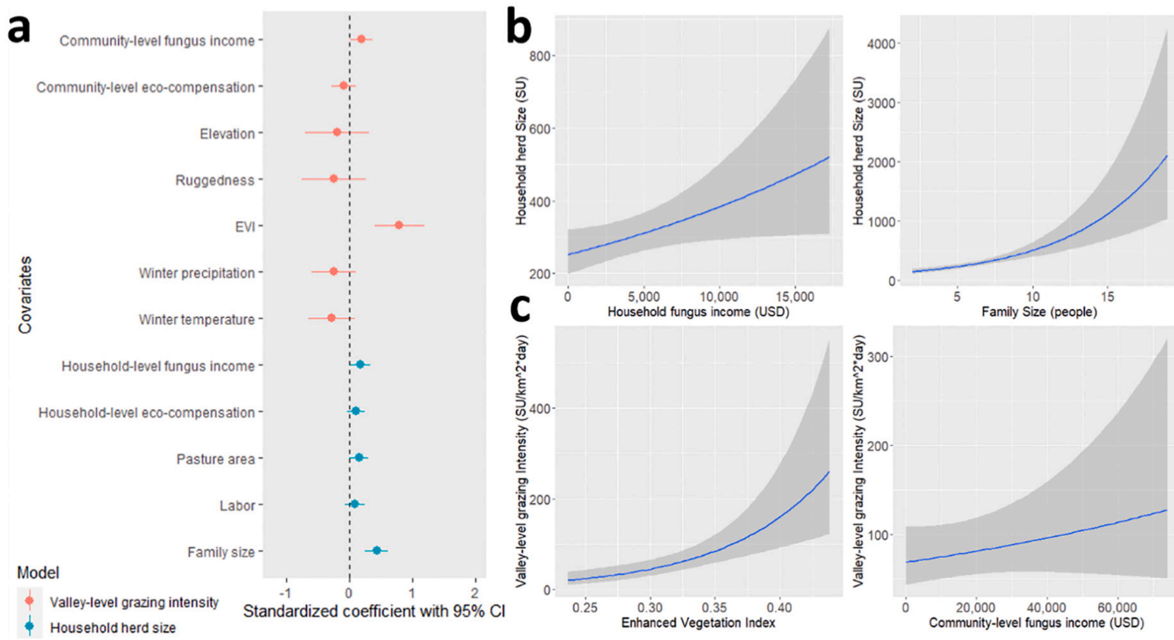

Fig. 3. Valley-level grazing intensity and household herd size explained by (a) all covariates, their standardized coefficients and 95% CI (95% CI not crossing the zero line indicates significant relationship), (b) response curves of the significant covariates (b and c).

Table 1
Mean and standard deviations of topographic variables, baseline grassland Enhanced Vegetation Index (EVI) and current grazing intensity (GI) for the three grassland classes and their statistical differences.

Variable	Biomass decreasing (D)	Unchanged (U)	Biomass increasing (I)
Elevation	4584/251 U 0.00*, I 0.00*	4622/289 I 0.00*	4735/215
Slope	22/11 U 0.11, I 0.00*	22/11 I 0.00*	24/11
Aspect	203/112 U 0.00*, I 0.00*	176/100 I 0.00*	160/73
EVI	0.29/0.12 U 0.34, I 0.00*	0.28/0.13 I 0.00*	0.23/0.11
GI	104/104 U 0.13, I 0.00*	98/100 I 0.00*	90/92

* Significant difference detected.

which we averaged into the final model. All 5 covariates (fungus income, eco-compensation, family size, labor force and pasture size) remained in the final model. Coefficients in the final model showed that eco-compensation has no significant relationship ($p = 0.14$) with household herd size, whereas family size ($p = 0.00$) and fungus income ($p = 0.04$) had significant positive relationships with household herd size (Fig. 3a, Table S3). Larger families with higher fungus income tend to have more livestock (Fig. 3b, Table S3).

The valley-level grazing intensity was significantly linked with forage condition and fungus income. The model selection process produced only one top-ranked model (ΔAICc ≤2), in which grassland coverage was excluded while other 7 covariates were retained. Coefficients in the top model again showed no relationship between eco-compensation and valley-level grazing intensity ($p = 0.37$). Forage condition over the last 5 years (indicated by EVI, $p = 0.00$) and community-level fungus income ($p = 0.04$) had significant positive relationships with grazing intensity (Fig. 3a, Table S3). Valleys with better pasture and higher fungus income tend to have higher grazing intensity (Fig. 3b, Table S3).

3.3. Patterns of grassland biomass change

We found that compared to the other two categories (biomass increasing and unchanged pixels), biomass decreasing pixels were significantly lower (p = 0.00) in elevation and had significantly more (p = 0.00) south-western facing trend. Compared to biomass increasing pixels alone, biomass decreasing tended to happen on gentler slopes (p = 0,00), areas with better forage condition (indicated by higher EVI value, p = 0.00) and higher (p = 0.00) current land-use intensity (Table 1). Negative change of grassland biomass was more likely to happen in lower-altitude pastures with gentler and southwestern facing slopes, better forage condition and more intensive livestock grazing, which indicated the negative impact of overgrazing on grassland conditions.

This pattern was in line with the interview results related to possible forage shortage. Eighty-eight percent of households bought supplementary feed for their livestock (mainly yaks) for winter/spring, which indicates the shortage of forage from most pastures. Over half of the households claimed the pasture was not enough even with supplementary feeding. Fifteen households reported that livestock starved to death over the last two years. Only three households reported renting pastures during bad years and seven households from Yunta reported hiring extra laborers with an average cost of 17,750 CNY per year.

3.4. The local perceptions on different cash income sources

Although not asked, at least 18 herders voluntarily expressed some concerns regarding non-pastoral incomes. They deemed these as unsafe and fragile income sources and did not consider the fungus economy as a long-lasting source of income source. They expressed the concern that someday the fungus resource would get exhausted or the fungus market would collapse, which is best reflected in the words of the leader of Dianda Village:

Nowadays with those new income sources, sheep are easily replaced. But yaks were different. The fungus is not a safe income. The wise people all bought in more yaks to safeguard their livelihood. Only unwise ones will sell all their yaks, move to cities and live on fungus income.

As to the eco-compensation fee, at least 27 herders worried that the government would stop their pasture contract someday in lieu of this payment. People of one village (Qianduo) initially refused to accept the compensation for several years due to this misunderstanding.

Most families (90%) sold off their sheep before the year 2014. A vast majority of families (84%) reported the reason for selling off sheep as being the high-cost associated with sheep raising (costly losses to predation by wolves, extreme snow events, and diseases). The other 16% attributed it to limited pasture and labor force.

Seventy percent of households didn't sell any livestock for years and attributed it to religious reasons (living Buddha said it's not a good thing to do). Interestingly, we found a pattern that villages with lower cash income from fungus depend more on livestock-selling. In the four villages with relatively lower household fungus income (USD 0–3138), 40% of the households did sell some livestock each year to supplement household for cash income. In the three villages with relatively higher fungus-income (USD 5039–12,753), 90% of the households claimed that they had almost completely stopped selling livestock. This pattern might be explained by a common and, often repeated survey response:

Now our cash income can cover most daily living expenses. We seldom sell any livestock due to our religion beliefs. Our living Buddha said killing the livestock unnecessarily was a sin. The only exception is when we really need some extra money for things like school fees and medication.

4. Discussion

The grassland eco-compensation program was designed as the largest economic incentive to reduce livestock grazing and restore semi-arid grassland ecosystems in China. However, the impact of supplementary incomes, including governmental subsidies to reduce livestock grazing intensity remains unclear. Although the reason behind grassland degradation is complex and could differ in different region (Harris, 2010; Lehnert et al., 2016; Wang et al., 2015), the pattern of change we found in grassland biomass at least indicated a negative impact of grazing on grassland condition at our study sites (decrease of biomass was linked with low-elevation pastures with highest productivity and most intensive grazing). This highlights the need to study the possible impact of extra cash incomes on grazing intensities based on robust field census data.

Our sampled livelihood interviews and livestock census showed that after controlling for other confounding effects, eco-compensation had no significant effect on livestock grazing intensity at both household and landscape scales, indicating they failed to offset traditional pastoral livelihoods. This is consistent with studies conducted in Inner Mongolia (Fan and Zhang, 2018; Yin et al., 2019).

Although the top-down designed grassland restoration policy seems reasonable, during our survey, we found that the grassland eco-compensation program was implemented as pure cash payments. These programs lacked well-communicated targets and assumed that pastoralism activity and livestock grazing pressure on grasslands would reduce as herder incomes would be subsidized. No contracts or agreements for the compensation were signed between herders and the government to clarify benefits, responsibilities, and expectations. In an attempt for fairness, all households were paid according to their pasture size or number of household members in most villages, not for any metric based on grazing intensity reduction. Given the lack of clarity, most herders could not identify which part of their pasture should act as no grazing zones and which parts should be grazed to a lesser extent. Similarly, 'ecological immigrants' who had their entire pasture banned from grazing, could still secretly rent or borrow their pastures to others (Fan and Zhang, 2018).

Further, fungus income had a positive relationship with livestock grazing intensity at both household and landscape scales. In conjunction with the local perceptions on different cash income sources, we suspected those fungus incomes might have actually subsidized pastoralism, which could have contributed to the increase of livestock biomass and yak number we found in Yushu Prefecture as shown in Fig. 1.

The local perceptions expressed by our interviewees provided two key clues to support our view. First, herders showed concerns to the security of both fungus and eco-compensation incomes and regarded yaks as a safer investment. Second, with non-pastoral incomes providing coverage for basic living expenses, most households no longer needed to sell livestock for these expenses. Religious values were often claimed as the reason for not selling livestock, although we suspect the ultimate cause might be the low profitability of pastoralism mainly due to two reasons. 1) Western development policy of China linked the local markets with national or even global markets through road construction. It forced the local livestock products to compete with products from all over the world, for which they had no advantage under this type of single-family, small-scale production. 2) The human population in Yushu more than doubled since the 1950s, which made the household herd size much smaller as the grassland carrying capacity didn't increase. This smaller stock of animals and thus a weaker base of subsistence entailed that not enough animal products are left to be marketed (Gruschke, 2011). However, with the support from other incomes, the non-profitable livestock rearing could be maintained by most households, which in a way subsidized pastoralism.

Interestingly, the herders treated yaks and sheep differently in our study area. Traditionally here, yak serve as a savings account, and insurance against natural disasters (mostly snow disasters), while sheep were treated as petty cash, and a means of payment for living expenses (Farooquee, 1998; Levine, 1999; Sulek, 2011), as sheep grow and reproduce faster. Compared to fungus digging which only last for one month a year, sheep raising is a high-input work year-round. As an introduced livestock from central Asia, sheep face various risks from wild predators, diseases, or extreme climatic events as identified by the interviewees. Unlike sheep that need to be followed all day long, adult yaks could be left in the mountains unattended as their large body size protected them from predators. Thus, while sheep could easily be replaced by other, less labor-intensive cash income sources, herders still tended to convert extra cash income into yaks as savings and insurance. Just as the head of Dianda village said, herders deem the new non-pastoral cash incomes as being unsafe, and felt safer to have savings in the form of yak herds, which traditionally serve as a symbol of wealth in the community (Nyima, 2014).

It is important to understand the original livelihood not just in the context of income, but also in the context of social systems, beliefs, and values, including traditional safety nets and sources of honor (Pollnac and Poggie, 2008). Unless the new income can fulfill all those functions in the same manner as the original, simply providing money will not be sufficient for replacing traditional livelihoods. Wicander and Coad (2015) reviewed eight livelihood incentive projects aimed to reduce hunting. They found that these projects provided supplementary sources of income but that hunting levels remained the same (Torell et al., 2010) and may even have encouraged hunting by releasing funds for the purchase of more efficient hunting equipment (Damania et al., 2005). Buzinde et al. (2014) found the Masai communities in Tanzania reinvested tourism income in cattle, which for them is a symbol of wealth and status, leading to overgrazing issues.

The current economic structure of the Tibetan herders shows a heavy dependence on a single natural resource, the caterpillar fungus. Considering the weak pastoral economy, caterpillar fungus could easily turn into a "resource curse" (Sachs and Warner, 2001) for the Tibetan Plateau. The grasslands were contracted to individual families in the 1990s (National People's Congress, 1985), at which time the livestock abundance in Sanjiangyuan Region had peaked (Fan et al., 2009). Children born after this period have had no additional land rights allocated, and are only able to share the pastures already contracted to the elder people from their families. The human population on the Tibetan Plateau has tripled since the 1960s, of which over 70% are pastoralists (Qinghai Province Statistics Bureau, 2015; Tibetan Autonomous Region Statistics Bureau, 2015). A sole dependence on livestock is presumably inadequate to maintain the livelihood of so many people. The fungus economy (and the eco-compensation) therefore has provided a crucial

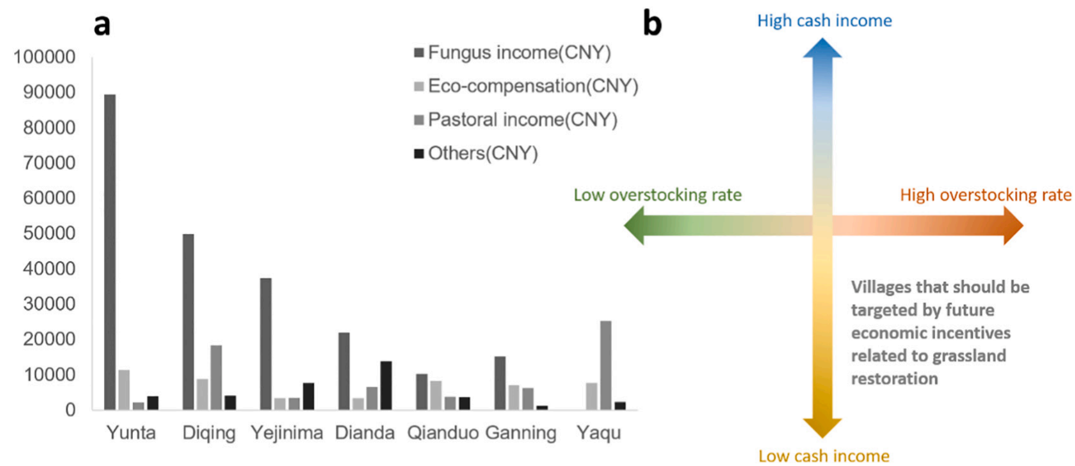

Fig. 4. a) Cash income structure of the seven villages. b) The suggested targeting areas of future economic incentive policies. In villages with a high cash income from other sources such as the fungus economy, the amount of grassland eco-compensation became negligible and will not be effective to promote a real behavior change. In villages with a low overstocking level, it would be a waste of budget to evenly distribute the eco-compensation into these areas.

new source of income to livestock herders on the Tibetan Plateau, though our results show that it did not alleviate the grazing pressure on the rangelands.

This study made a number of assumptions. First of all, without reliable historical data of grazing intensity to show its changing trend at household and landscape scales, it's hard to conclude any causal relationships between new incomes and grazing intensity. To overcome this weakness we included livestock density at the township level at the year 2011 (the year before the eco-compensation implementation) as one coarse baseline data in valley-level grazing intensity models. Second, we acknowledge there could still be other confounding factors we didn't measure that affected both grazing intensity and non-pastoral incomes at the same time (e.g. transportation convenience). Third, livestock will not use all areas within a valley uniformly, our model at the valley scale is a simplification of grazing intensity. Lastly, EVI only represents above-ground biomass change which is not necessarily a good indicator of forage/ecosystem condition (Hopping et al., 2018). For instance, a composition change from sedge/grass dominated meadows to herb/shrub-dominated meadows might indicate a degradation in forage quality while showing an increase of above-ground biomass (Karnieli et al., 2013). This concern is lessened at least to some extent as 1) we excluded shrublands in our analysis; 2) the degradation we observed in our study sites were mostly bare soils, herb-dominated patches only consisted a minor fraction of alpine meadows here.

4.1. Policy suggestions

Our results suggest that simply providing subsidies is not sufficient for replacing traditional livelihood (Bennett, 2008; Liu et al., 2008; Wang et al., 2016). In addition, extra cash income from other sources needs to be considered during policy implementation. In our case, fungus provided much higher income compared to other sources. It might have subsidized pastoralism and made the amount of grassland eco-compensation negligible compared to the high profit brought by fungus. Based on our results we suggested a more targeted eco-compensation weighted towards villages with low non-pastoral income and degraded grasslands (Fig. 4b), such as Yejinima, Dianda, and Ganning in our case, with clearly stated responsibilities and obligations, instead of the evenly distributed cash payment.

Considering the difficulties and high cost of monitoring conservation behaviors in remote areas, result-based payments might be a better alternative. Result-based payments have the benefits to create common goals between herders and policy-makers (Musters et al., 2001) and encourage innovations and collaborations in land management towards better financial rewards (De Snoo et al., 2013). While controlling for climate impacts, remote sensing data combined with ground truthing could be used as grassland restoration result indicators (Eckert et al., 2015; Javzandulam et al., 2005), without constraint on what restoration approaches was adopted at the local scale.

Cross-department collaboration in policy design and holistic planning of provincial budget among departments is needed in ecologically vulnerable regions. Since other types of governmental subsidies such as poverty alleviation funds, could also have similar effects as fungus income if not well designed with the consideration of ecosystem conservation. In this case caution is needed in other programs to avoid further subsidizing the original livelihood that might have accelerated ecosystem degradation.

5. Conclusion

Our study assessed the effectiveness of policy interventions that use economic incentives to encourage land use change, on a scale pertinent to land-use policy-making. Our results found that simply providing subsidies didn't have the intended effect of reducing land use intensity and might have even subsidized it, due to the intertwining of the original livelihood with traditional beliefs and value systems. The results and indications could also be applied to many other circumstances facing similar problems of agricultural subsidies.

CRediT authorship contribution statement

Lingyun Xiao and Zhi Lu conceived the ideas and designed methodology; Lingyun Xiao, Xiang Zhao, Suonancuo Mei collected and prepared the field data; Lingyun Xiao analyzed the data and led the writing of the manuscript. Hao Wang prepared the Enhanced Vegetation Index data and Ziyun Zhu provided the official livestock data in Yushu. All other authors revised and edited the drafts. All authors contributed critically to the drafts and gave final approval for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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