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Original Research

Risk-Overgrazing Relationship Model: An Empirical Analysis of Grassland Farms in Northern China

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ABSTRACT

Empirical studies of risk-induced overgrazing have been rarely reported in northern China grasslands, thus, the risk indicators that act as proximate drivers of herders stocking rate (SR) are poorly understood. This paper investigates the impact of the Chinese Grassland Eco-compensation Reward and Subsidy Policy implementation (2011–2015) in Inner Mongolia on overgrazing as a consequence of SR. We used a linear mixed-effects model to develop the relationship between SR and designated risk indicators. The best-fit models obtained were used to evaluate the role of each indicator on the tendency of herdsmen to overgraze grasslands. The major drivers of SR identified prior to the policy implementation are the area of grassland owned, living expenses, and the area of grassland rent-out. Subsequent to the policy implementation, the area of grassland owned and the area of grassland rent-in emerged as the principal factors that induce herders to use high SR on grassland, indicating the persistence of overgrazing. Our most promising finding was that the policy eliminated living expenses from the factors that compel herdsmen to use high SR on grassland. This represents a significant positive impact on herders' welfare, which is one of the objectives of the subsidy and reward policy. Therefore, to sustain the success recorded in the first phase of the policy implementation, we advocate for an improved grassland rental market that will encourage livelihood diversification, better funding, herdsmen cooperation, consideration of local ecological condition and herders' perspective in policy design, and consistent education of herders' about the merits of reducing SR on grasslands. To achieve the desired target of reducing overgrazing, we recommend an independent process of policy inspection that will strengthen effective bottom-up feedback and village level governance.

Introduction

Payment for ecosystem services (PES) or eco-compensation programs have increasingly been adopted as a development and policy tool for the protection of global ecosystems (Bremer et al., 2014; Kronenberg and Hubacek, 2013; Muradian et al., 2013; Wunder, 2008), for poverty alleviation in rural communities (Costanza et al., 1997; Kinzig et al., 2011), and for enhancement of the sustainability of ecosystem services (Kosoy and Corbera, 2010; Pappagallo et al., 2018b; Yin and Zhao, 2013). These conservation and restoration driven programs, however, have generated debate among scientists and some criticism that the policy tool ignores multiple social, cultural, and political factors (Pappagallo et al., 2018b), and may overestimate the breadth of positive results (Muradian et al., 2013). Other researchers, however, support its potential for effective conservation and sustainable land management (Byakagaba et al., 2018; Engel et al., 2008; Kinzig et al., 2011; Nduhiu et al., 2016; Wunder, 2007). Potential driving factors for participation in the PES program include an alternative source of livelihood, the high valuation of program output, low opportunity costs associated with land-use regulation (Bremer et al., 2014), a combined increase in livestock and multiple ecosystem services (Huntsinger, 2013), and improved education of ranchers/pastoralists to be more active and environmentally aware managers of land resources (Ferranto et al., 2013). Earlier reports have shown that the success of PES programs is dependent on equitable satisfaction of participants (Bremer et al., 2014; Luck et al., 2009), livelihood improvement, and non-monetary benefits accruable to ecosystem providers (Grima et al., 2016). Unequal bargaining power, however,

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is perceived as a negative resultant effect of PES implementation (Kronenberg and Hubacek, 2013).

Similar to PES programs in other parts of the world, eco-compensation programs in China are more common in agricultural, forestry, and watershed areas (Pappagallo et al., 2018b; Zhen and Zhang, 2011) than the rural pastoral areas. The policy in China is more encompassing than PES programs in other countries owing to its top-down strategy of implementation and a built-in penalty concept (Zhen and Zhang, 2011). In rangeland and pastoral settings, many ecosystem services are also largely dependent on the interaction between livestock, ranchers/pastoralists, and the ranching communities (Huntsinger and Oviedo, 2014). Pastoralists derive the larger share of their income from livestock grazing, and their livelihood is directly impacted when herd size declines. Thus, the adoption of an eco-compensation policy to compensate pastoralists to reduce resource-use intensity through payments, to foster the protection of rangelands, and enhance ecosystem functions (Li et al., 2015). Although the eco-compensation policy is recommended as a good approach to ecosystem conservation (Huntsinger, 2013), the workability of these management schemes in pastoral rangeland settings is reportedly limited (Pappagallo et al., 2018b).

To enhance herders' income and welfare, and foster national ecological integrity, the Chinese government through the Ministry of Finance established the Grassland Eco-compensation Reward and Subsidy Policy for grassland protection (hereinafter referred to as subsidy and reward policy) which includes the subsidy for grazing ban, balancing livestock utilization with grass production, and forage grass improvement (ADB 2016). The first round of this policy was implemented from 2011 to 2015. During this period, the government provided funds for implementation with the objective of reducing overgrazing through a reduction of livestock numbers to restore degraded grasslands (Gaodi et al. 2015). The eight major grazing provinces in China (including Inner Mongolia), covering a total of 250 million ha of grassland and that account for approximately 80% of Chinese grasslands, received CNY13.64 billion ($2.0 billion) subsidies in 2011, CNY15 billion ($2.2 billion) in 2012, and CNY16 billion ($2.4 billion) in 2013 (ADB 2016). Households are compensated based on the area of grassland owned and the type of grassland (for example, meadow vs desert steppe).

Despite the implementation of the subsidy and reward policy program in Inner Mongolia, degradation remains a severe ecological problem in more than one-third of the grasslands (Batunacun et al., 2018; Ministry of Agriculture of China, 2016), with a much less degree of conservation and restoration as intended (Liu et al., 2018). Earlier reports (Conte, 2015; Liu et al., 2018) have shown that 10% of the total grassland areas were degraded in the 1970s, 30% in the 1980s, 50% in the 1990s, and about 90% by the end of the 20th century. The increasing level of degradation is caused by climate change (Wei et al., 2020), human activities (Harris, 2010; Zhou et al., 2014), policy changes (Liu, 2017), and overgrazing due to increased livestock number (Hou et al., 2014; Waldron et al., 2010). For example, sheep units (SU = a 50 kg ewe with lamb consuming 1.5 kg day^{-1}; used for standard conversion of other livestock species) increased by 143.6 M from 1947 to 2009, pastoral households increased by 458,000, and total human population increased by 18.5 M within the same period (Briske et al., 2015). Studies on the financial implication of overgrazing vs. sustainable grazing are limited in Inner Mongolia. Kemp et al. (2013) proposed a 50% reduction in livestock number as the financially optimum stocking rate (SR) in the desert steppe. Li et al. (2018b) found that maximization of livestock revenue is restricted by not only SR, but also the frequency of weather disturbance, feed expense ratios, and availability of forage land to provide supplemental feed. Besides, many studies have shown that the ensuing financial loss from overgrazing is several times that of sustainable grazing in the short and long-term (Holechek et al., 2010; Hooper and Heady 1970; Vallentine, 2001).

Risks associated with livestock production on grasslands vary with geography and local management (Harr et al. 2014, Jokhio et al. 2016). For example, historical grassland management strategies across the various steppes in northern China encourage herdsmen to increase animal numbers, to compensate for unforeseen climatic conditions and extreme weather events such as drought, dzud, and dust storm (Harr et al. 2014, Li et al. 2018a), that could result to livestock mortality. Across northern China, less capital accumulation, a lower area of grassland owned, and lower livestock number increase the economic vulnerability of grazer households (Ding et al. 2014). Pastoralists in this region are faced with other risks such as low hay yield (Anderson et al. 2010) and limited access to sown pastures (Du et al. 2016, Li et al. 2018a). Overgrazing as a result of risk aversion has been under-reported in Inner Mongolia grasslands, which may signify a lack of information on risk indicators that act as the proximate drivers of herders SR. Hence, there is a need for empirical studies to better understand the drivers of overgrazing as a function of SR, and how pastoralists react to socio-ecological policies enacted for environmental sustainability (Li et al. 2007, Li et al. 2018a).

Moreover, it is unclear how well the subsidy and reward policy has encouraged herders to reduce overgrazing on Inner Mongolia grasslands which are the principal objectives of the policy. Therefore, we address the following research questions: 1) what are the risk indicators that compel herders to use high SR on grassland both before and after the implementation of the subsidy and reward policy and 2) does herder participation in the subsidy and reward policy lead to a reduction of livestock numbers, and consequent overgrazing? To achieve this, we explored select risk indicators associated with SR using empirical data sourced from grassland herding households in Inner Mongolia. Using linear mixed-effects models, we developed the relationship between the selected indicators and herders' SR to uncover the drivers of herders' overgrazing behavior and to predict the relative contribution of each risk indicator towards overgrazing. Our models provide valuable insight into the impact of the subsidy and reward policy on livestock reduction, and how local grassland managers' risks associated with SR and overgrazing could be addressed using policy instrument to foster a reduction in livestock number, and subsequently reduce grassland degradation in northern China.

Methods

Study area

The Inner Mongolia Autonomous Region (IMAR) lies in the northern part of China, bordering the Republic of Mongolia and Russia to the northeast. It is dominated by varying grassland ecosystems (meadow, typical, sandy, desert, and desert steppe) (Fig. 1), accounts for 12% of China's total land, and management is dominated by traditional livestock production, including cattle, sheep, and goats (Kemp et al. 2018). Increasing numbers of animals and herding households has led to degradation in this region. The growing season is from May through September and grassland productivity declines from the east to the west (see supplementary material). The average frequency of drought is 3.16 times each year (Lei et al., 2015) and herders' coping mechanisms include selling of livestock (Li and Huntsinger, 2011), purchase of supplementary feed (Briske et al., 2015), housing livestock in shed and seeking other grazing resources (Hou et al., 2012), and engagement in off-farm jobs to compensate for the ensuing economic loss (Hou et al., 2012; Wan et al., 2016).

The Household Contract Responsibility System (HRCS) was implemented in the 1980s to increase livestock production in

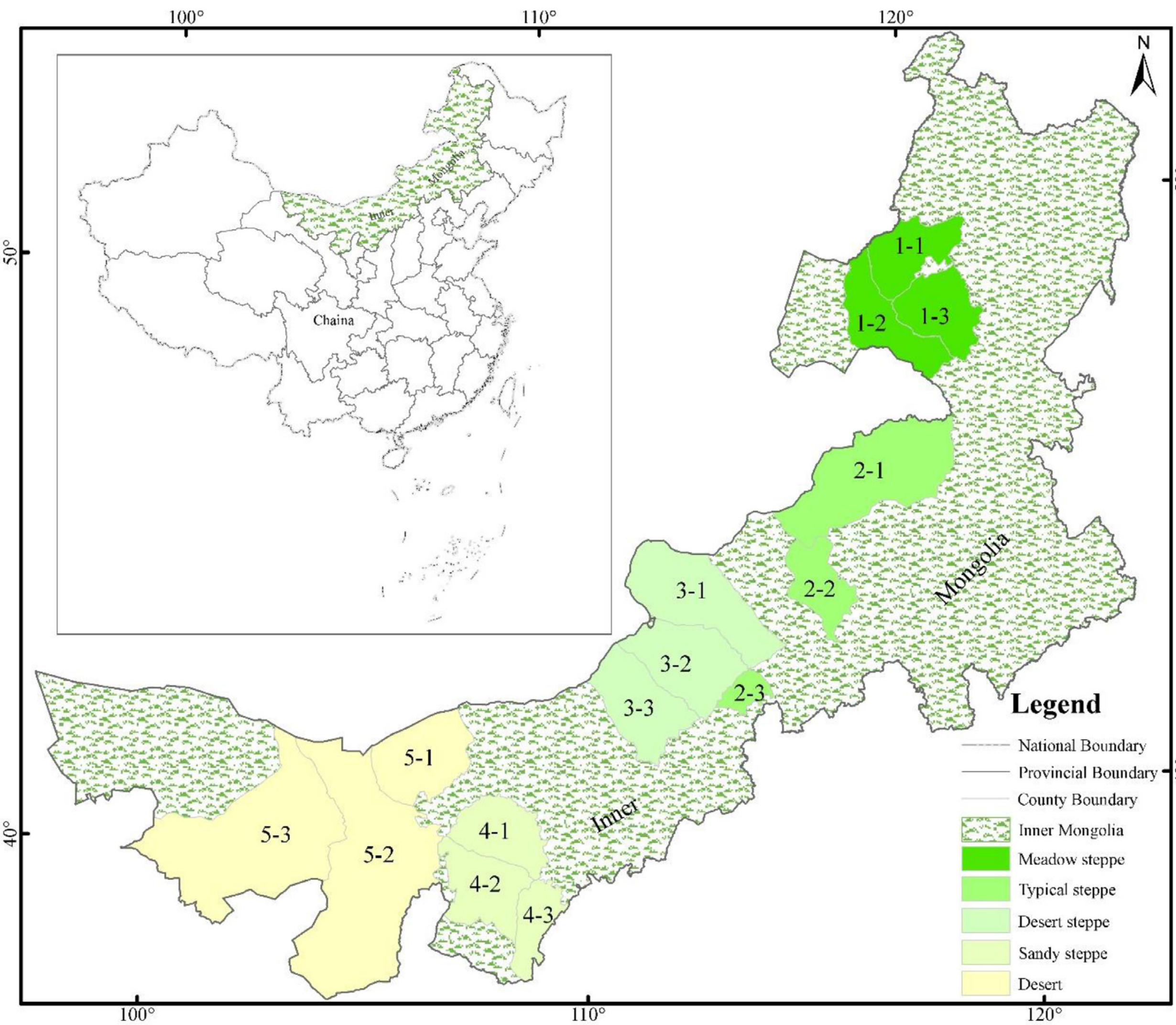

Fig. 1. Map showing study areas across different grassland types. 1-1 Chen Barag Banner; 1-2 Ewenke Banner; 1-3 Xin Barag Left Banner; 2-1 East Ujimqin Banner; 2-2 Xilin hot; 2-3 Xianghuang Banner; 3-1 Sunite Left Banner; 3-2 Sunite Right Banner; 3-3 Siziwang Banner; 4-1 Hangjin Banner; 4-2 Otog Banner; 4-3 Uxin Banner; 5-1 Urad Back Banner; 5-2 Alxa Left Banner; 5-3 Alxa Right Banner.

pastoral areas (Hou et al. 2014). This policy originated from a previous Crop Farmer Program (Li et al., 2007b). During the implementation, both animals and grazing lands were distributed among herders (Du et al., 2017; Li et al., 2018a; Li and Huntsinger, 2011) using the “people six, livestock four (ren liu xu si)” or “people seven, livestock three (ren qi xu san)” mode of distribution (Tan et al., 2017). The IMAR was one of the first regions where this policy was implemented (Li and Huntsinger 2011) and herders SR has continuously increased since the policy was enacted, leading to unsustainable grassland use and management. Further, significant changes in landscape pattern, with attendant modification of ecosystem structure and function have become widespread in the region.

Household survey

Our survey focused on the impact of ‘Balancing Grass and Animal’ and ‘Forbidden Grazing’[1] policies on livestock reduction by herders participating in the subsidy and reward program in the IMAR. In 2010 and 2015, a pilot version of the questionnaire was implemented with 30 and 20 households respectively. Following each survey session, the questionnaire was improved according to the suggestions and comments of the respondents. The modified questionnaire was subsequently used to interview 1000 and 900 households’ in 2010 and 2015 (see appendix A), while 850 questionnaires from the same households in both years were used for model construction. The model construction involved developing a probabilistic model to describe the relationship between the dependent (i.e., SR) and independent variables (i.e., risk indicators). Respondents were selected using a stratified random sampling procedure from meadow, typical, sandy, desert, and desert steppe, with three counties representing each grassland type. From each county, six villages were selected and 10 households were randomly sampled. Translators with detailed village understanding were hired, trained, and subsequently assisted with the data collection (Yin et al. 2018). The different sections of the survey questionnaire used in this study were:

(i) Socio-economic characteristics: including herding households’ age, ethnicity, and educational level.

[1] Forbidden grazing refers to the legislation of grazing exclusion on severely degraded grasslands with the aim of restoring the landscapes into a productive state. It is also referred to as grazing ban.

(ii) Grassland information: including the area of contracted grassland (i.e., owned), hay area, artificial pastures, and grassland rent details.
(iii) Livestock information: details of the number of heads of the different classes of animals raised by herders. The number of animals other than sheep was converted to sheep units using standard sheep conversion factors for China (see supplementary material).
(iv) Expenditures: information about household expenses such as living cost and medical expenses.

Statistical analyses

All data analyses and generation of figures were conducted in R version 3.5.1 (R Core Team 2018). Stocking rate was log-transformed to improve normality before analyses and subsequently used as the response variable in the prediction models. We employed linear-mixed effects models using the 'lme' function in the 'nlme' library (Pinheiro et al. 2018). The area of artificial grassland nested within grassland type was treated as random effects if supported by model selection (Hautier et al. 2014). We used a 95% confidence interval to draw inference for the fixed effects in each model using the "intervals" function. Marginal and conditional coefficients of determination (r^2) were derived using "r.squaredGLMM" function from the "MuMIn" package (Jaeger 2017). For each period of the year (early and middle), we analyzed the response of SR to socio-ecological variables used as predictors (Table S2). We fitted all candidate models using stepwise elimination of fixed effects with maximum likelihood method and assessed statistical significance by likelihood ratio tests (L ratio) (Vogel et al. 2012). We compared all the fitted models based on Akaike Information Criterion (AIC) and selected the model with the least weight across the years (Pinheiro and Bates, 2001). This generated different final models for each year (Table S8, early-2010, $n = 756$; Table S9, mid-2010, $n = 756$; Table S10, early-2015, $n = 841$; Table S11, mid-2015, $n = 791$). We obtained a broadly consistent result for each year (Tables S8–S11), so we only present the figures in the main text. The ensuing equations for 2010 and 2015 are shown below:

$$SR_{ear-2010} = GO + GROA + LivExp \quad (1)$$

$SR_{ear\text{-}2010}$: Stocking rate at early 2010
GO: The area of grassland owned by herders
GROA: Grassland rent-out area
LivExp: Living expenses

$$SR_{mid-2010} = GO + GROA + LivExp \quad (2)$$

$SR_{mid\text{-}2010}$: Stocking rate at mid-2010

$$SR_{ear-2015} = GO + GRIA \quad (3)$$

$SR_{ear\text{-}2015}$: Stocking rate at early 2015
GO: The area of grassland owned by herders
GRIA: Grassland rent-in area

$$SR_{mid-2015} = GO + GRIA \quad (4)$$

$SR_{mid\text{-}2015}$: Stocking rate at mid-2015

Results

Drivers of stocking rate before the subsidy and reward policy

Our results showed a negative relationship between SR and the area of grassland owned by herders prior to the implementation of the subsidy and reward policy (early-2010 and mid-2010; Figs. 2a and 3a; and Tables S8–S9). Similarly, the area of grassland rent-out had a negative relationship with SR (Figs. 2b and 3b, Tables S8–S9). Notably, there was no difference (compare slope in Figs. 2b and 3b) in the area of grassland rent-out by herders within the year 2010, implying that lower area of grassland rent-out influence higher SR in that year. In contrast, there was a positive relationship between living expenses and SR (Figs. 2c and 3c). The observed similarity in herders living expenses across the year (compare slope in Figs. 2c and 3c; Tables S8–S9) showed that higher living expenses propel herders to use higher SR on grassland.

Drivers of stocking rate after subsidy and reward policy implementation

Following the implementation of the subsidy and reward policy, our fitted models (early and mid-2015) indicate that the area of grassland owned by herders remains influential on SR, with a negative relationship. As earlier remarked, the lower area of grassland owned leads to higher SR (Figs. 4a and 5a). Correspondingly, the area of grassland rent-in had a weak negative relationship with

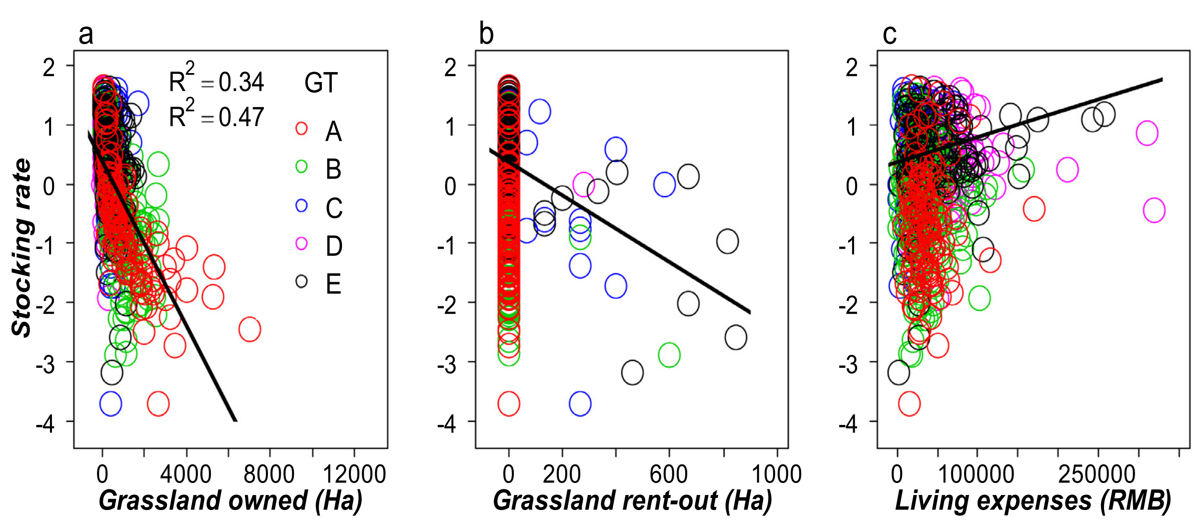

Fig. 2. The relationship of stocking rate with the area of grassland owned (a, left column), the area of grassland rent-out (b, middle column), and living expenses (c, right column) in early-2010 across different grassland types in northern China. (A): desert; (B): desert steppe; (C): meadow steppe, (D): sandy steppe; and (E): typical steppe. Marginal (fixed effects; upper) and conditional (fixed and random effects; lower) R^2 are given for the model.

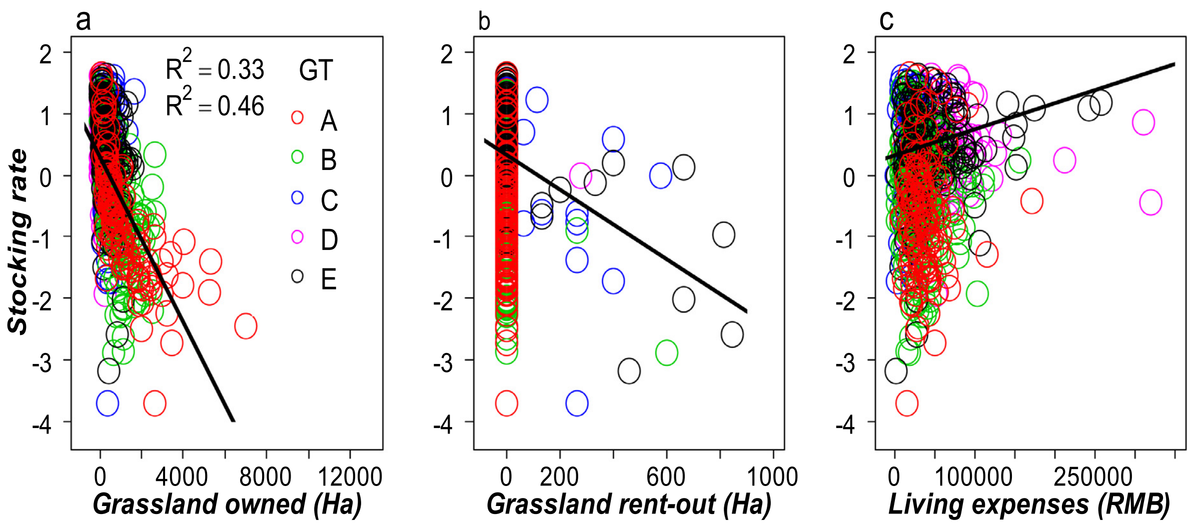

Fig. 3. The relationship of stocking rate with the area of grassland owned (a, left column), the area of grassland rent-out (b, middle column), and living expenses (c, right column) in mid-2010 across different grassland types in northern China. (A): desert; (B): desert steppe; (C): meadow steppe, (D): sandy steppe; and E: typical steppe. Marginal (fixed effects; upper) and conditional (fixed and random effects; lower) R^2 are given for the model.

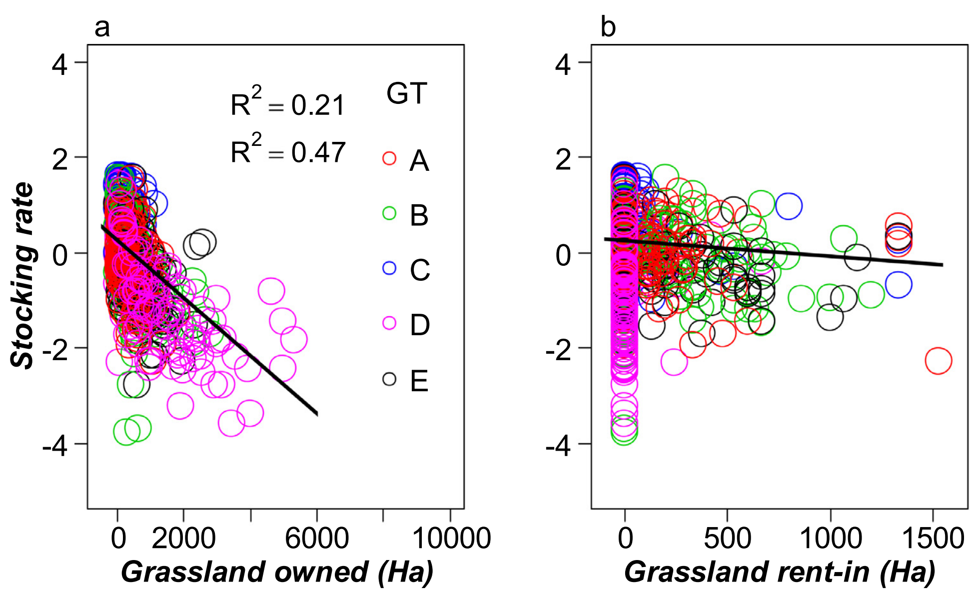

Fig. 4. The relationship of stocking rate with the area of grassland owned (a, left column) and the area of grassland rent-in (b, right column) in early-2015 across different grassland types in northern China. (A): desert; (B): desert steppe; (C): meadow steppe, (D): sandy steppe; and (E): typical steppe. Marginal (fixed effects; upper) and conditional (fixed and random effects; lower) R^2 are given for the model.

SR, indicating that lower area of grassland rent-in leads to higher SR (Figs. 4b and 5b).

Drivers of stocking rate: 2010 vs 2015

In both years, the area of grassland owned by herders' was negatively correlated with SR (Figs. 2a–5a; Tables S8–S11). The area of grassland rent out and living expenses were not supported by model selection in 2015. Thus, they had an insignificant effect on the SR after the policy implementation. Rather, the area of grassland rent-in, in addition to the area of grassland owned by herders predicted SR in 2015. The lower area of grassland rent-in promotes higher SR on grassland (Figs 4b and 5b), indicating a state of disequilibrium between herders' livestock number and the combination of contracted and rented grasslands.

Discussion

Drivers of stocking rate before the subsidy and reward policy

Herders in IMAR maintain a large number of animals for wealth accumulation and buffering of future risk, rather than animal production efficiency (Ellis and Swift 1988, Allsopp et al. 2007). The area of grassland owned by herders' predicted SR at both early-2010 and mid-2010 (pre-policy period). Specifically, the best-fitted models (Figs. 2a and 3a) in 2010 converged and showed that lower area of grassland owned leads to higher SR and this conforms to our hypothesis. This finding supports the earlier report by Crosson et al. (2016) that sustainable animal production is dependent on the size of grazing land and the number of animals stocked. We infer that the smaller area of grassland owned by herders is the major underlying reason contributing to herders using higher SR

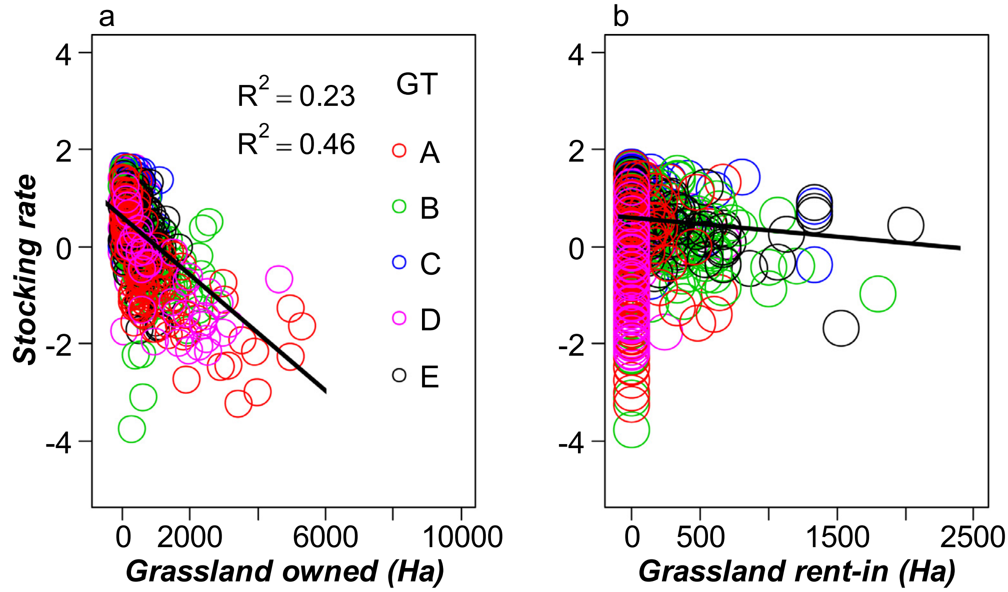

Fig. 5. The relationship of stocking rate with the area of grassland owned (a, left column) and the area of grassland rent-in (b, right column) in mid-2015 across different grassland types in northern China. (A): desert; (B): desert steppe; (C): meadow steppe, (D): sandy steppe; and (E): typical steppe. Marginal (fixed effects; upper) and conditional (fixed and random effects; lower) R^2 are given for the model.

on grassland, as a response to earlier grassland policies, and to the detriment of ecological integrity.

We suggest that, when the number of households depending on grassland resources decline, the pressure is relieved on the land resulting in more uniform distribution of grazing pressure, thereby leading to ecological improvement (Conte 2015, Du et al. 2016; Kemp and Michalk, 2011). Our empirical models showed a confluence in the area of grassland rent-out by herders. The lower area of grassland rent-out leads to higher SR, implying that those who rent out a small part of their land tend to use high SR that increases grazing pressure on the remaining grassland resources. On the other hand, herders who rent out a substantial part of their land aid ecological construction through a reduction in SR. However, herders in the latter category could be defined as having: (1) a diversified source of livelihood that warrants a reduction in the time invested in animal production; (2) a few livestock; (3) less capability to graze and (4) other relevant situations that could prevent grazing (Tan et al. 2017).

Besides the supply of forage required by livestock, grasslands in IMAR also support the livelihood of herdsmen in this region (Zhen et al. 2010). Paudel Khatiwada et al. (2017) noted that livelihood profiles are variable and differ across wealth, age groups, and gender. The result from our fitted models showed that higher living expenses lead to higher SR, thereby increasing the risk of overgrazing the grasslands. However, Fernandez-Gimenez and Batbuyan (2004) suggested that herders believe degradation is either unavoidable or a temporary and reversible phenomenon. Similarly, Gaodi et al. (2015) reported that herders hold the opinion that grassland degradation is a result of climate change, but not anthropogenic in nature. Herdsmen strongly perceive that the main function of grassland is to provide their livestock with feed, and in turn, derive their own means of livelihood from the animals by attempting to maximize livestock numbers at the expense of rangeland and soils (Harris 2010).

Drivers of stocking rate after subsidy and reward policy implementation

The profitability of livestock production is primarily driven by SR, and the accelerating increase in livestock numbers across the pastoral regions of China is seen as a rational strategy towards reducing risk (Conner 1991; Squires and Limin 2010). Nevertheless, other scientists have implicated that economic reforms have also contributed to higher livestock numbers in China (Li et al., 2015; Zhang et al., 2004). Our results confirm that the area of grassland owned is negatively correlated with SR and overgrazing in the IMAR. This shows that land ownership is a key factor affecting the success of the subsidy and reward policy (Pagiola, 2008). However, Li et al. (2015) reported that rangeland policies in China are less likely to achieve conservation and restoration outcomes because their focus is on ecosystem service outputs, and do not consider feedbacks from the social and ecological systems that generate these services (Bremer et al., 2014; Huntsinger and Oviedo, 2014; Li et al., 2015; Pappagallo, 2018a; Yin and Zhao, 2013). Subsidies may therefore be a medium of aligning private and social costs and benefits in a society, but the compensation received by herders to reduce overgrazing is not in tandem with the observed outcome of the land managers' behavior (Pigou, 1932). This implies that the overgrazing behavior of herders is socially sub-optimal (Zhen and Zhang, 2011). Herders' participation in the reward and subsidy program may only be a commitment to the government policy directive (i.e. ecosystem buyer) (Huntsinger and Oviedo, 2014), and not for the purpose of livestock reduction and reduction in SR and overgrazing, per se. Briske et al. (2015) and Yin et al. (2018) noted that, rather than maximizing animal numbers per unit area as presently practiced by herdsmen in IMAR, efforts should be directed towards educating the pastoralists on how to shift from a 'keeper' to 'producer' model of livestock management as a plausible way of further improving herders' income, and reducing SR and overgrazing that leads to grassland degradation (Fig. 6).

For a long time, academia has been concerned with land tenure in pastoral areas, since pasture leasing plays a key role in a herders' dependence on the local ecosystem (Du et al. 2016, Liu et al. 2017). Our fitted models (Figs. 4b and 5b) showed a weak negative relationship between SR and the area of grassland rent-in by herders. This indicates that the subsidy and reward policy has resulted in minimal success by empowering the majority of herders to rent-in small areas of grassland (Figs 4b and 5b) with a marginal effect on overgrazing. Therefore, relative to the environ-

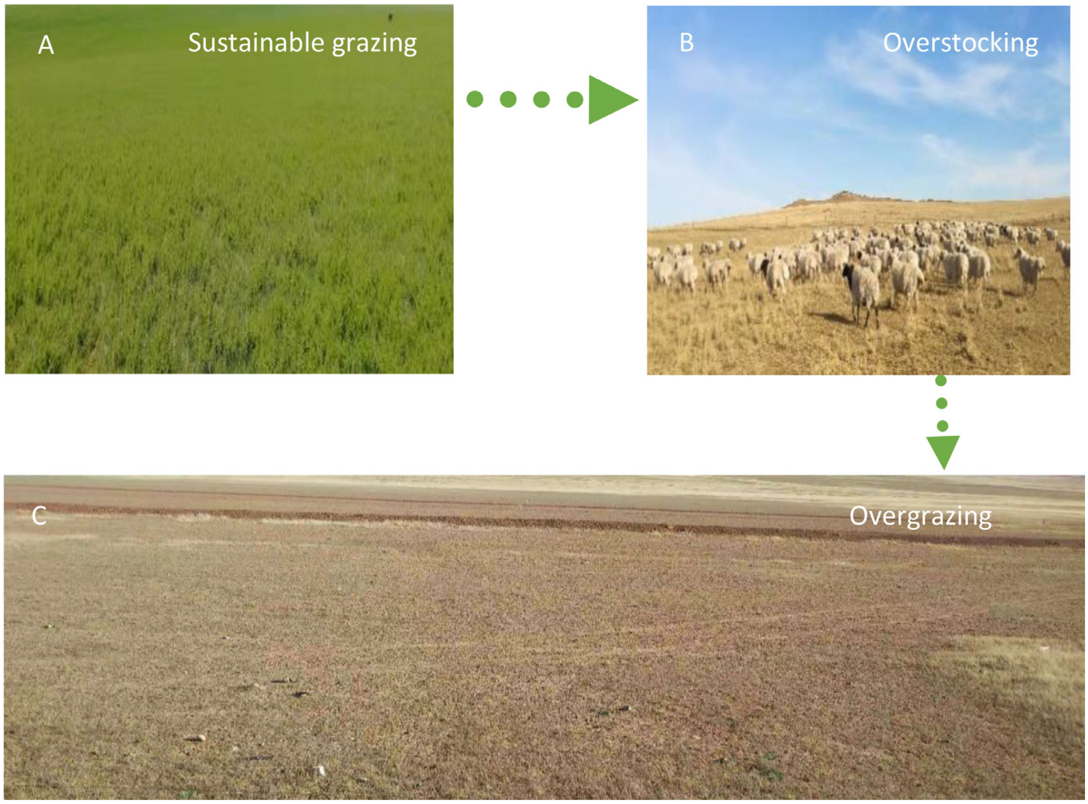

Fig. 6. The process of grassland degradation by livestock grazing. 'A' depicts the scenario of sustainable grazing with ample forage resources, 'B' shows overstocking of livestock on grasslands, while 'C' indicates a degraded grassland that results from overstocking (i.e., high stocking rate) and overgrazing.

mental challenges faced by herders across the grasslands of IMAR, rent-in of additional land remains a plausible strategy increasing both the household income and ecosystem health. Additional emphasis, however, should be placed on education of both herders and government officials in the value of limiting SR to the available ecological carrying capacity (Jiang, 2006; Waldron et al., 2011; Yin and Zhao, 2013) to prevent grassland degradation from overgrazing.

Implications of subsidy and reward policy on stocking rate

The results of our models showed that the major underlying factor that consistently influences the SR used by herders across Inner Mongolia grasslands is the area of grassland owned. Across the first phase of the subsidy and reward policy implementation period, we observed that the majority of herding households still own a small area of grassland, but raise higher livestock numbers (Figs 2a–5a), indicating continuing livestock intensification. This finding supports the idea that PES or eco-compensation programs cannot solve the problem of sustainable rangeland management in isolation (Li et al., 2015; Pappagallo et al., 2018b), but require other supporting conditions such as improved land tenure regimes and rangeland governance systems (Pappagallo et al., 2018b), education and technical advice to pastoralists on how SR affect financial returns (Holechek et al., 2010; Huntsinger and Oviedo, 2014; Kemp and Michalk, 2011; Vallentine, 2001), and strengthened feedback from social and ecological systems (Byakagaba et al., 2018; Hruska et al., 2017; Li et al., 2015). We contend that the competing focus of the subsidy program (environment and poverty alleviation), and unequal sharing of economic and ecological benefits (for example, between protectors and beneficiaries) (Zhen and Zhang, 2011) are partly responsible for the minimal success shown in reducing animal numbers and overgrazing. Similar results (Kinzig et al., 2011; Wunder, 2008) have been documented in the PES literature. Hence, there is a need for more effort from policymakers to continuously update the incentive structure (Yin and Zhao, 2013) and implementation strategy (Muradian et al., 2013) of the subsidy and reward policy in support of the policy objectives.

Renting of grassland among herdsmen could be viewed as a response mechanism to the sedentarization and enactment of grassland laws (Conte 2015) that have deprived pastoralists of their traditional mobile grazing practices that allow for flexible seasonal utilization of grassland resources. In 2010, the SR was correlated with the area of grassland rent-out, while in 2015, SR was correlated to the area of grassland rent-in. This indicates that, although herders rented-out a small part of their land but maintained a high SR in 2010 (pre-policy period), a transformation occurred in 2015 following the subsidy and reward policy implementation where herders sought to rent-in more land thus reducing grazing pressure on their own land. This indicates that the policy also resulted in an additional source of income and investment for herders. Land transfer contracts range from 1–4 years in Inner Mongolia (Li et al. 2018a) which allows for the possibility of lessors regaining their grassland use right within the first phase of the policy implementation. Further, to avoid and/or reduce unsustainable land use among herdsmen, the conservation of rented grassland should also be addressed in the subsidy and reward policy program (Li et al., 2018a; Wunder, 2008).

Earlier reports (Li et al., 2007a; Li and Huntsinger, 2011; Li et al., 2015) have shown that PES or eco-compensation policies enacted to reduce grassland degradation through livestock reduction can conflict with the welfare of participants or ecosystem service providers. The subsidy and reward policy, however, may have decoupled living expenses from the factors that propel herders' to use high SR on grassland, resulting in livestock intensification in smaller areas of grasslands used for animal production by the pastoralists. Grima et al. (2016) analysed 40 different PES schemes in Latin America and found that livelihood improvement, operation of PES schemes for a longer term (10–30 years), non-cash compensation, and the involvement of a private organization (for example, NGO) in PES implementation enhanced the success of the policies. The subsidy and reward policy investigated in this study, however, only addressed one of these points by eliminating living expenses from the factors affecting SR via the provision of new stable income for the pastoralists (Wunder, 2006). Notably, our study focused only on the first phase of the subsidy and reward policy (2011–2015). The marginal success recorded across this period could be sustained and improved by strengthening the policy through increased funding (Muradian et al., 2013), regulation of the transfer of grassland use rights (Huang et al. 2017), and the adoption of non-financial or in-kind payments (Bremer et al., 2014; Kronenberg and Hubacek, 2013; Wunder, 2008)**.** Our results corroborate the earlier report (Gao et al. 2016) that herders are not yet satisfied with the current grassland protection policies, suggesting that more effort is needed to attain further reductions in SR, and overgrazing in particular, across the grasslands of northern China.

Conclusion

The strength of designated risk indicators in predicting SR was investigated during the first phase (2011–2015) of the Chinese Grassland Eco-compensation Policy in IMAR. Our empirical models showed that the major drivers of SR prior to the policy implementation are: the area of grassland owned, living expenses, and the area of grassland rent-out. Subsequent to the policy implementation, the area of grassland owned and the area of grassland rent-in emerged as the principal factors affecting SR, indicating the persistence of overgrazing. Unlike earlier reports (Kronenberg and Hubacek, 2013; Li and Huntsinger, 2011; Wunder, 2008), our most promising finding was that the policy reduced the impact of living expenses as a factor that compels herdsmen to use high SR on grassland, which represents a significant positive impact on herders' welfare. It is noteworthy, however, that this paper is based on a survey of participants in the PES program, and does not include any specific information linking stocking rate changes to the actual on the ground degradation across the study areas.

Reduction of overgrazing across the pastoral regions of IMAR seems more difficult than it was perceived at the initial implementation of the subsidy and reward policy. Our results indicate that the majority of herders' retain a high SR on small grassland areas despite deriving stable additional income from the policy implementation. This suggests the need to modify the top-down pattern of implementing grassland laws and policies in IMAR (Waldron et al., 2011; Zhen and Zhang, 2011) and perhaps implementing non-cash compensation for rangeland conservation and restoration. We advocate for an improved grassland rental market that will encourage livelihood diversification, the inclusion of ranchers/pastoralists perspective in policy design, and consistent education of herders' about the merits of reducing SR on grasslands, including its effect on financial returns; to sustain the success recorded in the first phase of the policy implementation. To achieve the desired target of reducing overgrazing in this region, we recommend an independent process of policy inspection that will strengthen bottom-up feedback and village level governance. Further studies are required to identify and develop the next generation of conservation-driven policies for sustainable rangeland management.

Declaration of Competing Interest

None.

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Supplementary materials

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