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Livelihood risks impact livestock reduction behavior of herders: evidence from Inner Mongolia, China

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We analyzed the primary livelihood risks faced by livestock-herding households across six counties and three grassland types in Inner Mongolia. The major livelihood risks were natural, market, financial, and policy. These risks are influenced by changes in stocking rate (SR), which are critical for controlling livestock numbers and averting risks associated with overgrazing in natural grasslands. We propose a correction method for SR based on hay purchase from a survey of 450 herders. We compared the distribution of households' SR after the correction and used a multiple linear regression model to empirically test the effect of livelihood risks on SR. The empirical model passed robustness test and the regression results of variables were robust. SR declined across grassland types after hay purchases. The SR of the meadow steppe was reduced by 35%, typical steppe by 23%, and desert steppe by 32%. Various factors affected changes in SR, including ecological subsidies to household income, timely access to market information, and annual livestock losses. We discuss implications of our findings for policy, market transactions, livestock insurance, social security, and formal credit systems in pastoral areas.

KEYWORDS

grassland degradation, livelihood risk, herders, adaptive management, animal husbandry system, Inner Mongolia

1. Introduction

Grasslands are one of the six natural resources in China that serve important ecological and economic functions in strategic locations. In northern China, Inner Mongolia grasslands are the prominent natural resources primarily used for livestock production and ecological security (Xie et al., 2019; Huang et al., 2021). The grasslands also serve as a key area for the implementation of China's "One Belt and One Road" initiative and a bridgehead for the country's opening to the north (Xu et al., 2016). Over the years, grassland degradation occurred at various levels owing to the interaction between multiple factors, such as climate change and unsustainable human use, arousing great concern in domestic as well as international academic and political circles. As the basic unit of livestock production, herding households are exposed to severe natural risks, which overlap with other livelihood risks from economic, social, and policy aspects. Consequently, the livelihood vulnerability of herding households has increased, severely affecting their livelihood security (Wang, 2013). Continuous global warming has led to the frequent occurrence of abnormal climate events (Bai et al., 2018; Walsh et al., 2020). Vulnerable herding households are gradually being subjected to the severe impact of the superimposed effect of livelihood risks, restricting the sustainable development of grassland pastoral areas. In this sense, a scientific analysis of the primary livelihood risks faced by herding households in the region and their coupled relationship with herder's overgrazing behavior could provide insight into the direction of socio-economic development in the Inner Mongolia pastoral areas while harmonizing the nature-human relationship.

Herding households adopt a single strategy to cope with risks, and livestock serve as a measure of their wealth. However, overgrazing has been recognized as a major and direct cause of grassland degradation in northern China (Ding et al., 2022). Therefore, in the process of exploring policies to address grassland degradation, the Chinese government's initial action was to reduce livestock numbers during policy implementation. Recent research on grassland management has focused on effectively reducing livestock numbers using different approaches. These include measuring the impact of livelihood capital on the willingness of herding households to reduce livestock numbers using the vulnerability analysis framework (Xie et al., 2018; Fu et al., 2021) and analyzing the impact of the grassland ecological conservation subsidy and incentive policy (GECP) on households' overgrazing behavior (Jimoh et al., 2020a) and income (Wang et al., 2017; Yin et al., 2019; Zhou and Zhao, 2019). Another approach is to determine how climate change risks affect grassland livestock production systems and reduce livestock numbers (Crook et al., 2020; Feng et al., 2021). Thus, the impact of prevailing livelihood risks on livestock production systems has become an integral part of herding households' production decision-making, which merits research efforts for sustainable grassland management.

In recent years, the productivity of natural grasslands is insufficient to adequately supply livestock, and purchasing forage has become a key means to support the sustainable development of animal husbandry (Wang J et al., 2016; Wang Z et al., 2016; Zhao et al., 2019; Jimoh et al., 2020b). Purchasing hay for feeding livestock will increase labor force and economic input, aggravating the livelihood burden of herders. Anyway, it is an adaptive livelihood strategy embedded in traditional animal husbandry production system (Zhou and Du, 2014). The natural grassland is not consumed by livestock during the feeding period. Hence, the use of hay as a supplementary feed reduces the grazing pressure on grasslands to some extent. However, Jimoh et al. (2020b) reported that feed supplementation, including the use of hay, is not a driver of herders' overgrazing behavior. The new regulations of Inner Mongolia Autonomous Region regarding grass and livestock balance, grazing prohibition, and rest grazing in 2021 also indicated to the possibility of increasing livestock numbers in pastoral and semi-pastoral areas by providing supplementary feed to animals. In this context, there is a need to develop novel approaches to estimate the stocking rate (SR) on natural grasslands. Therefore, this study was designed to scientifically explain the causes of herders' continuous overgrazing behavior. We developed a novel approach to obtain the corrected SR combined with hay purchases by herders, thereby providing a basis for optimizing grassland conservation policies.

In this study, we used three grassland types in the central-eastern part of Inner Mongolia as the research area. Herding households engaged in livestock production were interviewed and the primary livelihood risks facing them were summarized. We calculated the adjusted SR using the hay purchased outside the herding household to establish a risk index system for quantitative analysis to determine the core factors driving the changes in herding households' SR. Furthermore, we documented responses of households to the identified risks. The risk control paths were explored for effective livestock reduction, aiming to provide recommendations to the government on how to strengthen the protection of the grassland environment using policy instruments.

The remainder of this paper is structured as follows: Section 2 introduces the materials and methods; the results are presented in Section 3; Section 4 provides the discussion, and Section 5 describes the management implications of the study.

2. Materials and methods

2.1. Study area

Inner Mongolian grasslands differ in productivity and abundance from east to west. In this sense, the landscape is designated as meadow, typical, desert, steppe desert, and sandy grassland. In this study, we considered three grassland types (meadow, typical, and desert), for the household surveys and data collection (Figure 1). The meadow grassland area has an annual rainfall of 350–500 mm, and is rich in forage species. It is dominated by perennial bunches and rhizomatous grasses, and its primary plants are *Stipa baicalensis*, *Stipa grandis* and *Leymus chinensis*. In the typical grassland area, the annual rainfall is 250–450 mm, mostly concentrated in summer; the spring is relatively dry. The annual rainfall in the desert grassland is less than 200 mm. The vegetation is composed of small perennial grasses, and the primary plants are *Stipa klemenzii* and *Stipa breviflora*. The area shares a boundary with one of the ten sandy areas in China, Hunsandak Sandy Land. This region is characterized by a dry climate, severe sand desertification, and frequent sandstorms.

2.2. Data collection

The data used in this study were collected during the household survey conducted by a team of socio-ecological researchers in the meadow steppe (MS), typical steppe (TS) and desert steppe areas (DS) of Inner Mongolia from September to November 2018. The time period involved in the interview questions was the previous year. Prior to this, the investigators received three days of systematic training on using questionnaire terminologies, research objectives, and the techniques for collecting data from respondents. During the research period, the project leader supervised the participants weekly to ensure data accuracy. Stratified random sampling method was employed to select the sampled herding households. Two banners (counties) were selected in each grassland area; two soums (townships) in each banner, and three gachas (natural villages) in each soum, with 8–12 herding households interviewed at each gacha. Questionnaires were administered using the Participatory Rural Appraisal (PRA) method, and information was collected using a face-to-face approach combined with semi-structured interviews (Li and Jeff, 2019). Interviews with herders were conducted separately without any involvement of

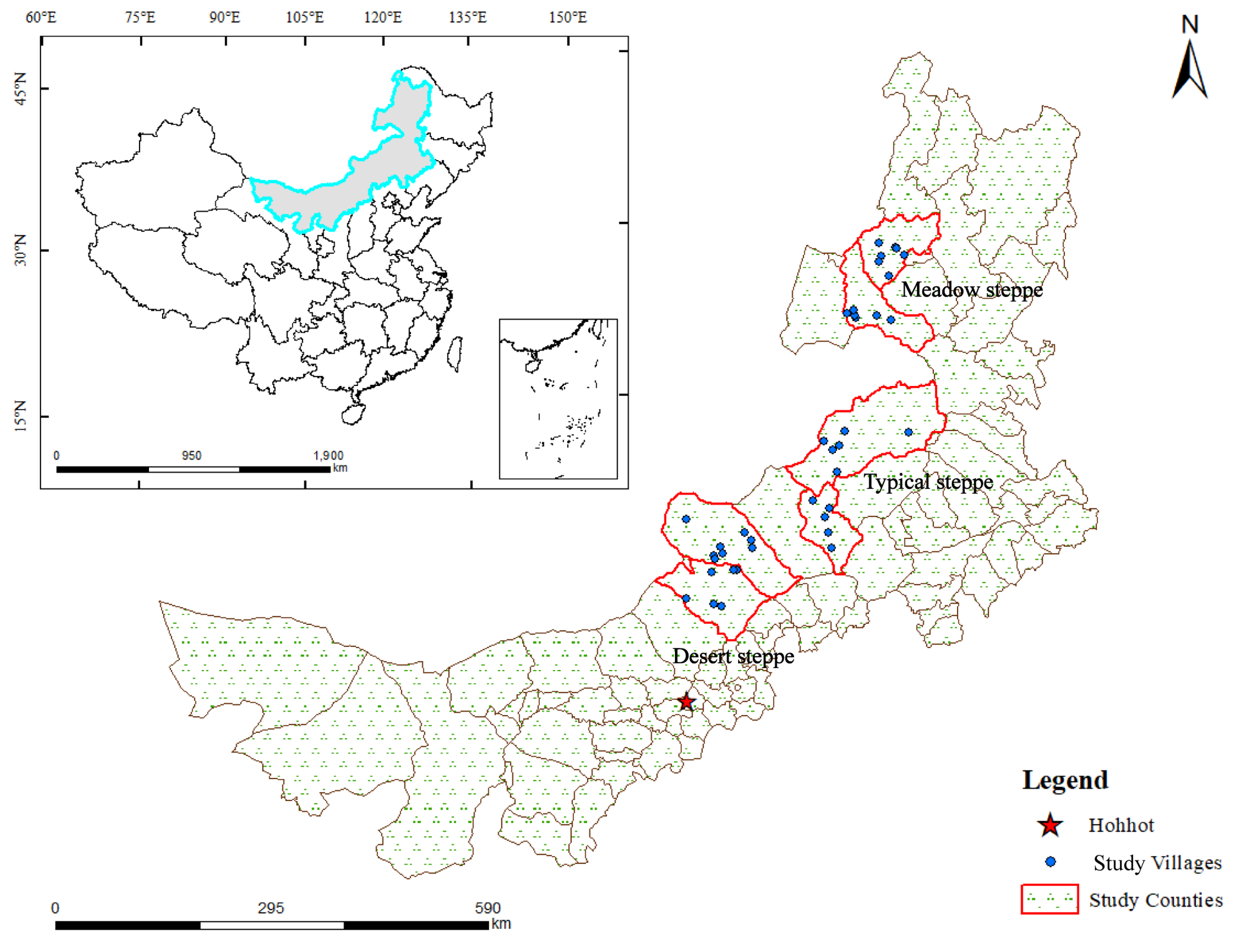

FIGURE 1
Map showing study areas.

government officials. The interview sessions lasted for approximately 1–2 h on average per respondent.

Following the successful completion of the household survey, the raw data were entered into Excel to generate a database for the study. The database was reviewed for coherence and quality by eliminating questionnaires with missing data and quality-related issues. We obtained 450 valid responses for this study. The distribution of valid responses was as follows: 125 of meadow steppe, 137 of typical steppe, and 188 of desert steppe. The survey content primarily included demographic characteristics, income and expenditure, livestock numbers, the area of contracted and rented pastures, and the various livelihood risks encountered by the herding households. The basic characteristics of the sample herders are listed in Table 1.

All participants verbally agreed to be interviewed, and the confidentiality of their personal information was assured. Notably, the herding households in the research area were predominantly Mongolian. To overcome language barriers during the face-to-face interviews, local university graduates proficient in both Mongolian and Chinese were hired as interpreters. Furthermore, some of the researchers were Mongolians who double checked the accuracy and consistency of the translations. The herding households in the study areas were scattered with several fences built to demarcate the land under their use, making it challenging to determine their geographic locations. As a remedy, we collaborated with natives who were familiar with the routes of herding households to effectively locate them.

2.3. Dependent variable

The stocking rate is the primary entry point when discussing grassland degradation. The SR on herders' grassland was designated as the dependent variable. Furthermore, we used the amount of hay purchased by herding households during annual livestock production to account for livestock units to obtain a more accurate adjusted SR, representing a novel and reliable approach for studying grassland management. The definitions of each variable and the descriptive statistics are shown in Table 2.

2.4. Independent variables

2.4.1. Policy risk indicators (X1) and assumptions

The grassland ecological protection subsidy and reward policy implemented by the Chinese government since 2011 in the pastoral areas of Inner Mongolia can be classified into three categories. These include the grass-livestock balance policy, no-grazing policy, and rest

TABLE 1 Socio-economic characteristics of the sampled herding households.

Grassland type	Number of sample herders	Grassland area (hm^2)	Number of livestock (sheep unit)	Loan (Ten thousand yuan)	Proportion of hay expenditure	Household labor force
MS	125	366	215	21.42	32.3%	3.76
TS	137	419	319	13.84	38.6%	4.18
DS	188	664	188	9.85	43.2%	3.92

MS, meadow steppe; TS, typical steppe; DS, desert steppe.

TABLE 2 Definitions of model variables and descriptive statistics.

Variable dimension		Index	Type of variable	Description	Mean	Std
Dependent variable		Stocking rate	continuous variable	Actual value	0.9123	0.8520
Independent variables	Policy risks (X1)	Proportion of subsidy amount	continuous variable	Actual value	0.1860	0.1883
		Whether the subsidies are paid in time	Categorical variable	In time = 1; No = 0	0.3244	0.4687
	Market risks (X2)	Livestock prices	continuous variable	livestock prices (Yuan)	602.9213	1.0930
		Whether market access is timely	Dummy variable	Yes = 1; No = 0	0.6511	0.4772
	Nature risks (X3)	Degree of livestock loss	Rank variable	No loss = 0; Mild loss = 1; Moderate loss =2; Severe loss =3	0.7956	1.0352
		Drought perception	Dummy variable	Serious = 1; No = 0	0.7933	0.4054
		Snow disaster perception	Dummy variable	Serious =1; No =0	0.2622	0.4403
	Life risks (X4)	Household labor force	continuous variable	Actual number of labor force	3.8556	1.0963
		Is loan repayment stressful (Financial)	Dummy variable	Yes = 1; No = 0	0.5356	0.4993
		Marriage uncertainty	Dummy variable	Have = 1; No = 0	0.1244	0.3305
		Proportion of *per capita* expenditure on health and education in total income	continuous variable	Actual value	0.7265	0.1111

grazing policy (Adb, 2016; Jimoh et al., 2020a). The policy sets the SR and the corresponding economic compensation based on the herder's grassland areas. The subsidy income is distributed to herders via transfers and substantially contributed to households' total income (Hou et al., 2021). However, during the field interviews, we learnt that herders believe the amount received through the subsidy and reward policy is inadequate to compensate for the economic losses caused by the reduction of livestock or shed feeding of animals in response to the policy. For example, in one of the banners in the typical steppe, seasonal or rotational grazing policy that allows the grassland to rest is implemented in April and May every year, i.e., livestock are raised in captivity during this period, while the loans obtained by herders in the previous year are used to purchase winter forage. Therefore, herders describe the resting period as "A helpless period," and the subsidy funds are not released timely to meet herders' requirements. In this context, we measured the policy risk from the herders' perspective using two dimensions: The proportion of subsidy income to the herder households' income, and the timeliness of subsidy payment. Theoretically, the higher the proportion of subsidy income to the total income of herding households, the higher the chances of reducing livestock numbers. Timely disbursement of subsidy funds to herders would reduce the challenges of livestock production (e.g., seeking for loans), thereby increasing trust and compliance with the policy by reducing livestock numbers.

2.4.2. Market risk indicators (X2) and assumptions

In this study, market risk refers to the situation in which herders experience a loss in profit when selling their agricultural (e.g., livestock) products owing to changes in market prices, supply and demand fluctuations or other changes in the market environment (Zhang et al., 2010). Jimoh et al. (2021) reported that herders' perception of market risk differs owing to variation in local environmental and market situations across the grassland types in Inner Mongolia. With the development of the market economy and global trade, including the gradual changes in the dietary structure of people, the fluctuation in the market price of livestock products has become highly stochastic, coupled with the continuous drought on a large regional scale in the grasslands of northern China. Consequently, the decline in natural grassland productivity and insufficient grass production have led to an increase in the amount of hay purchased by herders, affecting household income (Jimoh et al., 2020b). Currently, livestock market has become a critical livelihood risk factor for herders. In this study, market risk was measured using annual standard sheep unit price changes and the timeliness of acquiring market information. Generally, the higher the market price, the higher the chances of herders selling their livestock to reduce the number of animals, and obtaining timely market information increases the chances of selling livestock at a reasonably high market price, reducing the uncertainty of income.

2.4.3. Natural risk indicators (X3) and assumptions

Natural risk refers to the occurrence and manifestation of catastrophic events (e.g., floods, dust storms, fire, droughts, and snowstorms) that adversely impact agricultural production, leading to difficulties in achieving agricultural production expectations and increasing the likelihood of economic losses for agricultural producers (Zeng and Mu, 2011). In the pastoral areas of Inner Mongolia, livestock rearing is the most profitable agricultural production activity for herders; however, it is vulnerable to natural risk threats. According to the literature and field research interviews, drought is the most frequent and serious natural risk affecting livestock production practices across Inner Mongolian grasslands (Miao et al., 2018; Tong et al., 2018). The occurrence of drought leads to a decrease in grassland productivity, a reduction in species richness, and frequent sand and dust storms. Snowstorm is also a major natural risk in Inner Mongolia, particularly in the meadow and typical steppes. Heavy snowstorm blocks roads connecting pastoral areas to towns, destroy livestock stalls, and restrict travel. We measured natural risk in three dimensions: the number of abnormal livestock deaths caused by natural risk, herders' perception of drought and snow severity. The higher the number of abnormal livestock deaths, the greater the economic loss suffered by herders, forcing them to consider reducing livestock number. An increase in drought levels propels herders to increase their livestock number to compensate for the attendant losses caused by drought. In this situation, livestock feeding is augmented with supplementary feed (i.e., hay purchase) (Jimoh et al., 2020b). The expected changes in households' livestock numbers under snow and drought severity are similar.

2.4.4. Life risk indicators (X4) and assumptions

The life risks faced by herders in Inner Mongolia include income instability as well as health, financial, and social risks. The interannual income of individual herding households is dominated by livestock production income, and unstable income directly leads to fluctuations in herders' living standards. Owing to climate change and overgrazing, grasslands are severely degraded, which leads to the leasing of land at a cheap price exacerbated by poor livestock growth. Consequently, herders' income fluctuates and the uncertainty of expenditure increases when herders switch their livelihood strategies (Ding et al., 2018).

With the improvement of residents' medical insurance system and the promotion and expanded implementation of poverty alleviation policies, residents of pastoral areas have access to basic medical services. However, the service access is impaired by regional characteristics such as inconvenient transportation facilities and information transmission, leading to untimely responses to health conditions. Moreover, the public medical services have limited mobility. Additionally, the cost of medical service has increased in the pastoral areas owing to the application of science and technology in medicine. Specifically, it is difficult for herders to cover the medical cost of major diseases impacting their living standards. During our field survey, some herders noted that it was difficult for them to overcome poverty because they had family members with serious illnesses. For instance, one of the respondents stated that:

> "I spent all my savings on my wife's illness. I earn a meager income by tethering other household's livestock. Owing to my situation, my daughter had to drop out of school and stay at home".

The situation is worse in the meadow steppe, where herders tend to borrow usurious loans, and annual and inter-annual repayments become a vicious cycle of debt (Sun and En, 2017; Zhang J et al., 2018; Zhang R et al., 2018). Herders tend to expand the scale of their livestock production to meet the pressure of loan repayments. This is achieved by increasing livestock numbers in anticipation of increased income to settle loans.

The problem of older people not getting married is another source of livelihood risk for individuals and their families. The greater the marital distress of herders, the more they tend to expand their livestock production scale, thereby increasing their income to solve marital challenges.

2.5. Statistical analysis method

2.5.1. Calculation of grassland stocking rate

We calculated the grassland stocking rate using the formula given below:

$$SR = n / s \tag{1}$$

Where SR denotes the stocking rate, n is livestock number converted according to standard sheep units (Rao et al., 2015; Yuan et al., 2016), and s is area of grassland owned by herders (i.e., the sum of contracted and rented grasslands).

2.5.2. Calculation of the adjusted stocking rate based on hay purchase

This model calculates the adjusted SR based on hay purchases by herders to obtain a more accurate representation of the prevailing situation in the pastoral areas of Inner Mongolia.

$$N = P / \left(1.8kg \times p \times 365days\right) \tag{2}$$

Where N denotes the expected livestock number to be reduced after hay introduction (sheep unit). P is herder households' expenditure on hay, p is the average price in the hay market in different regions, $1.8\,kg$ is the quantity of hay required to feed one sheep unit daily (Mao, 2015) and 365 refers to the number of days in a year. The data were standardized prior to calculation.

2.5.3. Multiple linear regression model

A multiple linear regression model was employed to analyze the relationship between changes in the adjusted SR and different livelihood risk factors, and the least-squares method was used for parameter estimation. Thus, the empirical model below was developed.

$$Y = F\left(X1 + X2 + X3 + X4\right) + \varepsilon \quad (3)$$

Here $X1 - X4$ denote the policy, market, natural, and life risk vectors, respectively, and ε is the random error term. The secondary variables for each risk vector are listed in Table 2.

3. Results

3.1. Analysis of herding households' livelihood risk perceptions and their distribution characteristics

Perceptions of livelihood risk is a prerequisite for adaptation and decision-making in livestock production (Li et al., 2014). We have differentiated the perception of livelihood risks among herders into the commonly feared (Figure 2) and the mostly feared (Figure 3), with the aim of obtaining more targeted answers.

Herding households in Inner Mongolia face several risks in their annual livestock production cycles. Figure 2 summarizes various types of risks perceived by herding households across the study areas in Inner Mongolia. The results indicate that herders are concerned about natural, market, policy, financial, and health risks. The top three livelihood risks faced by herding households in the meadow steppe are market, natural, and financial, accounting for 95%, 86%, and 62%, respectively. Table 1 indicates that the average loan obtained by herders in the meadow steppe is higher than that in the other two grassland types. In the typical grassland, the major livelihood risks faced by herders are similar to the meadow steppe, but the proportions differ. Market, natural, and policy risks top the list of livelihood challenges faced by herders in the desert steppe, accounting for 97%, 96%, and 57%, respectively.

The resource endowments and livelihood capital stocks of herding households differ. Correspondingly, the livelihood risks mostly feared by herding households during the livestock production cycle vary (Ding et al., 2018; Aribi and Sghaier, 2021). As depicted in Figure 3, households' concern regarding natural risk decreases in three grassland types. In the meadow steppe, the top three livelihood risks most feared by herding households are financial risk (29%), market risk (26%), and natural risk (14%), whereas the top three livelihood risks threatening herding households in other two grassland types are market risk, financial risk, and natural risk, respectively, but with different magnitude. The least feared livelihood risk faced by herding households in the meadow steppe is policy risk (1.6%), while pension (2.2%) and marriage (2.1%) risks are less challenging for herders in the typical and desert steppes, respectively. Identifying the livelihood risk types mostly feared by herders is crucial for developing effective policy.

3.2. Analysis of adjusted stocking rate and its distribution characteristics

The information gathered on hay market prices during field research shows that the average price in the meadow, typical, and desert steppes is RMB 500, 1,100, and 1,200/ton, respectively. Based on our calculation of the adjusted SR that considers hay purchase, a sheep unit is equivalent to RMB 329 spent on hay purchase in the meadow steppe, RMB 723 in the typical steppe, and RMB 788 in the desert steppe (Dong et al., 2022).

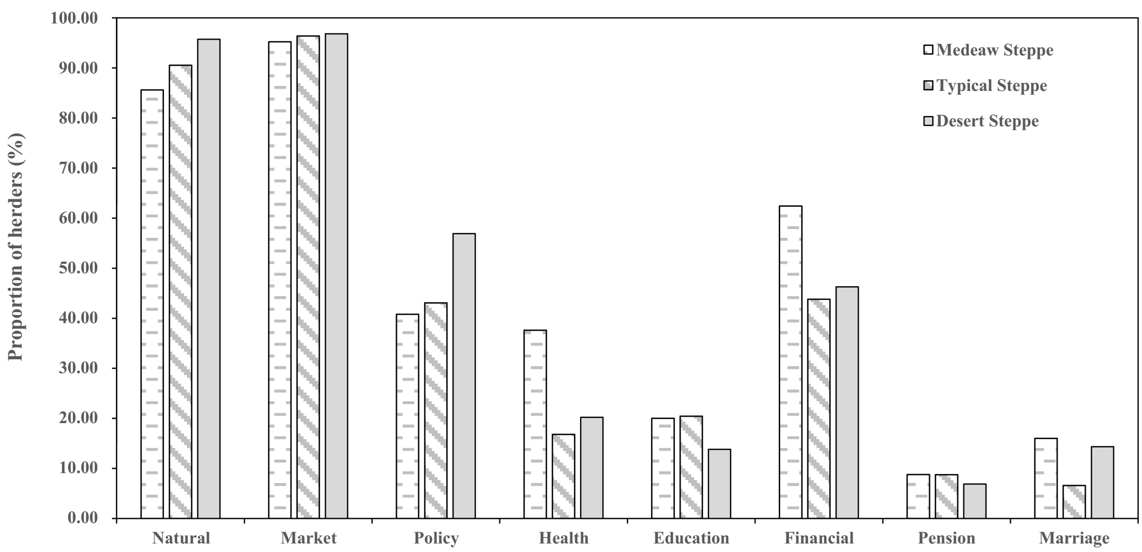

FIGURE 2
Types of livelihood risks commonly feared by herders.

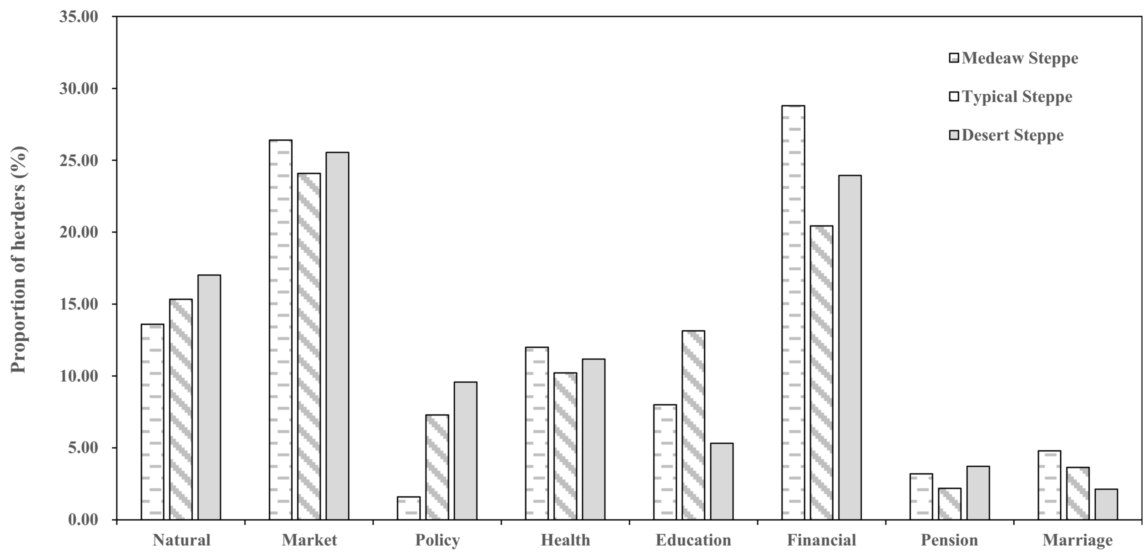

FIGURE 3
Types of livelihood risks mostly feared by herders.

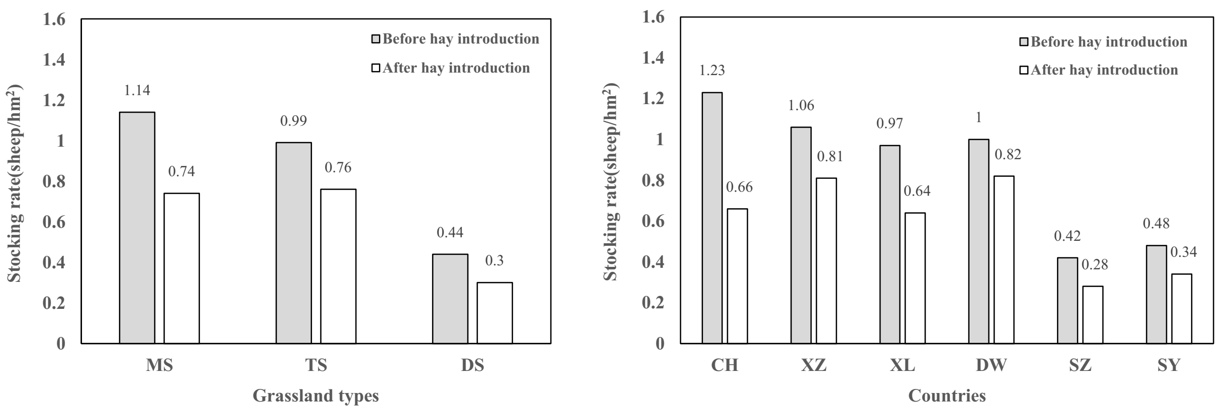

FIGURE 4
Herder's stocking rate across the meadow, typical, and desert steppe of Inner Mongolia. MS, meadow steppe; TS, typical steppe; DS, desert steppe; CH, Chenbalhu Banner; XZ, Xinbalhu Left Banner; XL, Xilinhot; DW, East Wuzhumuqin Banner; SZ, Sunit Left Banner; and SY, Sunit Right Banner.

The SR values in the meadow, typical, and desert steppes decreased after considering hay purchase (Figure 4). The SR values decreased by 35% in the meadow steppe, 23% in the typical steppe, and 32% in the desert steppe after considering hay purchase. Furthermore, the SR in Chenbalhu Banner and Xinbalhu Left Banner in the meadow steppe decreased by 46% and 24%, 34 and 18% in Xilinhot and East Wuzhumuqin Banner in the typical steppe, and 33% and 29% in Sunit Left Banner and Sunit Right Banner in the desert steppe, respectively. Moreover, we found that significant grazing pressure relief owing to hay purchases was in the order of Chenbalhu Banner > Xilinhot City > Sunit Left Banner > Sunit Right Banner > Xinbalhu Left > East Wuzhumuqin Banner.

Further analysis revealed that the SR in Chenbalhu Banner was 1.23 sheep units/hm^2 before considering hay purchases, which was higher than Xinbalhu Left Banner (1.06 sheep units/hm^2). After considering hay purchases, the SR in Chenbalhu Banner was lower than that in Xinbalhu Left Banner due to the larger purchases of hay in the former. In the typical steppe, the SR in Xilinhot (0.97 sheep units/hm^2) was lower than that in East Wuzhumuqin Banner (1.00 sheep units/hm^2). The SR followed a similar trend after considering hay purchases because herders in Xilinhot purchased more hay than their counterparts in East Wuzhumuqin Banner. Consideration of hay purchases is crucial for optimizing grassland management policies in future.

3.3. How livelihood risks impact adjusted stocking rate in Inner Mongolia

We employed Pearson correlation analysis on the variables included in the model and no significant correlation was found between the explanatory variables (See Appendix: correlation analysis). Multicollinearity refers to the distortion of model estimates and a reduction in model accuracy owing to the presence of highly correlated independent variables. All the explanatory variables in the model were tested for multicollinearity. The results showed that the maximum variance inflation factor (VIF) for all explanatory variables was 1.159, and the mean value was 1.061, which was lower than the threshold value of 10 for the presence of multicollinearity (Yang et al., 2012).

Five regression results were obtained from the model. First, all variables in the first step were introduced into the model, Model 2 excluded the presence of marriage distress indicator based on Model 1, Model 3 excluded the subsidy timeliness variable based on Model 2, Model 4 excluded the livestock price index variable based on Model 3, and Model 5 further excluded the drought impact severity variable based on Model 4.

The model regression results are shown in Table 3. The proportion of subsidy income to the total income of herding households ($p < 0.01$) affects the SR in all models. This implies that the proportion of subsidy income is an important and consistent factor related to herders' SR. The lower the proportion of subsidy income, the higher the SR used on grasslands. Similarly, timely access to the market ($p < 0.01$) affects the SR, showing a positive relationship. This means that the herder's easy access to the market propels them to increase their SR in anticipation of favorable market prices. The natural risk factors related to herder's SR across the models are annual livestock loss and the severity of snow disasters. These variables are positively significant at the 1% level. A high incidence of livestock loss (i.e., mortality) and snow disasters leads to a corresponding increase in the SR. There is a positive relationship between the household labor force and SR at the 1% statistic level, while the proportion of expenditure on health and education has a positive impact on the change of SR at a significant level of 5%. A higher number of labor force and proportion of expenditure on health and education propels herders to maintain a high SR. The pressure for loan repayment is significant ($p < 0.1$) only in Model 4, showing a negative relationship. This indicates that the lower the pressure of loan repayment on households, the higher the SR used on grasslands, which deviates from expectation.

3.4. Robustness test results

To examine the reliability of the regression results, with reference to existing studies (Wu and Lu, 2015; Qi and Du, 2017), overstocking rate (OSR) was selected as a proxy variable for stocking rate and the independent variables in the model were retested as shown below:

$$Y_{osr} = \beta_0 + \alpha X_1 + \gamma X_2 + \lambda X_3 + \pi X_4 + \varepsilon \quad (4)$$

Where Y_{osr} denotes herder households' OSR, $\beta_0$is the intercept of the regression line, α, γ, λ, and≠ denote the regression coefficients of each explanatory variable, respectively, ε is the random error term. The robustness test results are shown in the attachment. The regression results of models 6–10 are consistent with those of models 1–5 (See Appendix: robustness test results). The observed differences between

TABLE 3 Results of model regression.

Explanatory variable		Model 1	Model 2	Model 3	Model 4	Model 5
Constant term		1.04 (0.274)	1.02 (0.271)	1.07 (0.269)	0.78 (0.167)	0.70 (0.157)
Policy risk (X1)	Proportion of subsidy amount	−1.626*** (0.201)	−1.625*** (0.200)	−1.644*** (0.200)	−1.609*** (0.198)	−1.643*** (0.197)
	Whether the subsidies are paid in time	0.081 (0.076)	0.082 (0.076)			
Market risk (X2)	Livestock prices	0.000 (0.000)	0.00 (0.000)	0.000 (0.000)		
	Whether market access is timely	0.209*** (0.076)	0.210*** (0.076)	0.216*** (0.076)	0.216*** (0.076)	0.217*** (0.076)
Natural risk (X3)	Degree of livestock loss	0.077** (0.035)	0.077** (0.035)	0.075** (0.035)	0.084** (0.035)	0.085** (0.035)
	Drought perception	−0.118 (0.088)	−0.117 (0.088)	−0.121 (0.088)	−0.118 (0.088)	
	Snow disaster perception	0.185** (0.081)	0.183** (0.081)	0.183** (0.081)	0.189** (0.081)	0.194** (0.081)
Life risk (X4)	Household labor force	0.065** (0.032)	0.065** (0.032)	0.065** (0.032)	0.065** (0.032)	0.063** (0.032)
	Is loan repayment stressful (Financial)	−0.114 (0.072)	−0.113 (0.072)	−0.117 (0.072)	−0.119 (0.072)	−0.128* (0.072)
	Marriage uncertainty	−0.039 (0.108)				
	Proportion of *per capita* expenditure on health and education in total income	1.322*** (0.413)	1.341*** (0.409)	1.337*** (0.409)	1.356*** (0.410)	1.341*** (0.412)
R^2		0.287	0.362	0.417	0.445	0.503
Adj. R^2		0.269	0.328	0.375	0.413	0.468
F value		13.789***	15.185***	16.735***	18.559***	20.915***

Standard error in parentheses; ***, **, *, indicate significant at 1%, 5%, and 10% significance level, respectively.

the two sets of models are 1) the proportion of expenditure on health and education was significant at 5% in models 6–10 against the 1% level observed in models 1–5, and 2) the level of significance of the variables (1% vs. 5% vs. 10%) slightly vary, indicating that the conclusions drawn from this study are robust.

4. Discussion

In this study, we found that herders' perception of livelihood risks differed across the pastoral areas of Inner Mongolia owing to differences in climatic conditions and resource endowments (Dong et al., 2019). Different mechanisms and approaches for reducing livestock numbers have been studied extensively (e.g., Hou et al., 2014; Kemp et al., 2018; Jimoh et al., 2020a). However, livelihood risk, particularly compound risk (i.e., a mixture of different risks) is a key threat to the reduction of livestock numbers by herders. The occurrence of livelihood risks seriously affects the normal livestock production cycle. Therefore, herders are unable to develop long-term animal husbandry production plans to achieve sustainability, such as optimizing livestock structures or improving livestock breeds (Li et al., 2018). Herders increase the number of livestock to ensure normal living conditions for their families. Most grassland management policies in China were implemented using a top-down approach (Robinson et al., 2017), that failed to consider the requirements of herders. To be effective, decision-makers must conduct in-depth surveys on future grassland management efforts, consider the differences between various grassland types and regions, and implement specific and targeted grassland management policies. Reducing livestock numbers can be achieved by lowering livelihood risks and implementing adaptive coping strategies, that allow herders to reasonably plan their grazing activities to meet the goal of grassland protection.

The SR of herders in different grassland areas decreased to varying degrees after considering hay purchase. The SR of the sampled herders in the meadow steppe area reduced drastically compared with other grassland types after considering hay purchases. This indicates that the use of hay as a supplementary feed by herders in the meadow steppe had a high impact on alleviating grazing pressure of natural grasslands (Dong et al., 2023). The Meadow steppe is in the eastern part of Inner Mongolia, with high rainfall, rich vegetation composition, and higher productivity than the other two grassland types (Wang and Bai, 2008). Therefore, herders in this area can effectively alleviate ecological pressure on natural grasslands by combining *in-situ* grazing with supplementary feeding (i.e., hay). The impact of purchased hay on lowering the SR in the desert steppe was higher than that in the typical steppe due to low grassland productivity in desert grassland areas (Zhang J et al., 2018; Zhang R et al., 2018). To maintain or expand the scale of animal husbandry production, herders in this area purchased more hay than their counterparts in the other two grassland types. Consequently, the number of livestock reduced was also higher than that in the typical grassland areas. This reduces the grazing pressure on the desert steppe and allows it to recuperate, which is conducive to the sustainable utilization of grassland resources in this area. With the aggravation of drought in the pastoral areas of Inner Mongolia and the wide acceptance of hay as a supplementary feed, hay purchases have become the primary adaptive behavior of herders. Thus, it is necessary to focus on this new and emerging form of livestock production. Livestock lack access to *in-situ* grassland resources during feeding, making it important for policymakers to consider the purchase of hay as a supplementary feed when formulating a grass livestock-balance policy. However, the high cost of hay exacerbates the livelihood difficulties of herder households, and it is also necessary to strengthen the market management of hay circulation (Zhao et al., 2019; Feng et al., 2021).

The empirical results of this study indicate that various livelihood risk factors influence herders' grazing behavior, implying that livelihood risks affect households' livestock reduction decisions. Particularly, an increase in the subsidy income policy reduces the SR of herders, as reported in several studies (Wei and Hou, 2015; Wang J et al., 2016; Wang Z et al., 2016). Access to timely market information propels herders to retain more livestock to sell at a higher price. The extent of livestock loss and the severe impacts of snow disasters have increased the uncertainty of livestock production. Herders increase their livestock numbers to maintain a normal livelihood level, which is consistent with the findings of Bai et al. (2020). Presently, livestock production in Inner Mongolia still relies heavily on human capital investment (Sun and Hu, 2018) and is driven by short-term interests; the increase in the family labor force is consistent with increasing livestock numbers. The increase in medical and education expenditures has expanded the expenditure gap between herders' families, and animal husbandry production is the primary livelihood source of herders in Inner Mongolia (Dong et al., 2022). Therefore, herders tend to increase their livestock numbers to obtain more income and meet family expenditure requirements.

5. Management implications

The above analysis indicates that different livelihood risk factors affect herders' SR. Adjustments in the management of the market, life, policy, and natural risks are crucial for reducing livestock numbers and grazing pressure on grasslands. The following policy insights are drawn from this study.

(1) Increase subsidy policy incentives and innovate fund management mechanisms. Subsidy and reward policy substantially improved the welfare of herding households. However, planning long-term implementation is imperative. Given that a higher subsidy incentive can propel herders to reduce the SR, we recommend increasing the subsidy provided to herders. More importantly, subsidy incentives should be provided during critical periods of livestock production to help herders facing financial difficulties to avoid recurrent debts. Furthermore, it is necessary to actively promote the positive externalities of grassland ecological protection, gradually guide the establishment of a market-oriented and diversified ecological compensation mechanism, and broaden the sources of funds to reduce the burden on the central government. Simultaneously, the government should strengthen herding household supervision in areas where the policy has been implemented, pay attention to the oversight functions of grassland supervisors, and develop innovative management mechanisms to prevent ecological compensation funds from becoming mere welfare packages (Zhang et al., 2019; Hou et al., 2021).

(2) Improve the mechanism of livestock market transactions and enhance the level of information technology (IT) in pastoral areas. The government should be more active in the macro-control of livestock product prices and implement protected price acquisition for major livestock products. It is essential to improve livestock market regulations and orders and promote fair trade between sellers and buyers of livestock products. Furthermore, the government should consider providing subsidies for the outdoor purchase of supplemental hay during drought years and promote the long-term supply of production materials from agricultural areas to herding households. The accelerated construction of fiber-optic networks for communication in herding areas can improve IT use among pastoral households, thereby reducing asymmetry in market information acquisition.

(3) Deepen the reform of livestock insurance and strengthen the construction of the early disaster warning system. Promoting livestock insurance in pastoral areas can serve as a strong coping mechanism for natural disasters. This can be achieved by advocating for herders to purchase livestock insurance and introducing diverse packages to address their requirements. Notably, the government can share part of the premium subsidies to encourage participation. Early warning technology for natural disasters should be continuously improved, the support and supervision of local meteorological departments should be strengthened, and these departments should be supported in using advanced technology to make scientific, timely, and accurate forecasts of meteorological disasters. This allows herders to effectively schedule their production cycles to better cope with natural disasters. Monitoring of grassland pests, diseases, and rodents should be strengthened to reduce natural risks. Scientific measures for precise prevention and control should be implemented simultaneously.

(4) Improve social security and formal credit systems in pastoral areas. To avert the medical and educational risks of households, the medical service network, mobility, and quality should be expanded and improved according to the regional characteristics of pastoral areas. Additionally, a sound social security and medical insurance system should be established gradually. The financial organization system in the pastoral areas requires improvement through the expansion of the channels and functions of rural financial services, standardized private lending practices, and a focus on the examination of fixed assets of pastoral households and the overall labor capacity of families. The rigid age requirement for a loan should be relaxed (e.g., some regions stipulate that people over 60 years old are not allowed to take loans), the threshold of rural financial services should be lowered, and there should be a low-interest rate for pastoral households requiring loans owing to disasters caused by irresistible factors during their production cycles.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author. Requests to access these datasets should be directed to haibin3664@126.com.

Ethics statement

This study collected data through face-to-face interviews with participants and did not involve medical research on human subjects. We clearly informed participants the purpose of the research in the process of investigation to ensure their right to know. Interview was conducted with the consent of the participants.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1186899/full#supplementary-material

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