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Article

Improving herdsmen's well-being through scenario planning: A case study in Xilinhot City, Inner Mongolia Autonomous Region

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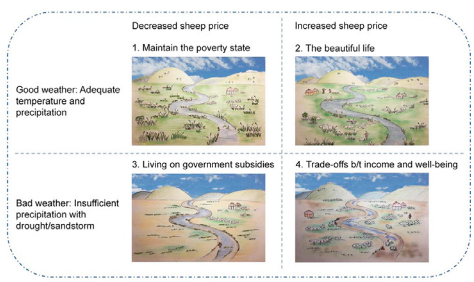
HIGHLIGHTS

- Both herdsmen's income and well-being improved during 1985–2005.
- The most important factor for herdsmen's well-being is income, mainly from husbandry.
- Husbandry income is mostly determined by weather condition and sheep price.
- Scenario analysis revealed divergence between income and well-being.
- Alternative income source and government subsidies are also important for herdsmen.

GRAPHICAL ABSTRACT



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ABSTRACT

Grassland ecosystems support well-being with food, shelter, income, and culture of herdsmen. While the association between ecosystem services and human well-being has been widely studied, such association is understudied in grassland ecosystems. This study aims to fill this gap through a case study of Xilinhot City, Inner Mongolia Autonomous Region, China. We examined the association between grassland provisioning services and herdsmen's well-being between 1985 and 2015 through participatory observations, interviews, surveys, and Bayesian belief network modeling. Considering the uncertainties of weather and sheep prices, we developed four scenarios to examine the future well-being of herdsmen. Our results show that the most important factor for herdsmen's well-being was income, which is highly sensitive to the market price of sheep and precipitation. Considering the uncertainties of sheep prices and precipitation, scenario analysis revealed a divergence between income and well-being. While herdsmen's income is most likely to increase with low precipitation and increased sheep prices, their well-being is most likely to improve with abundant precipitation and increased sheep prices. Based on our findings, we argue that developing alternative income sources (e.g., tourism), reducing dependence on government subsidies through commercial insurance, and branding lamb with grassland ecosystem to alleviate the impact of price fluctuations would help improve herdsmen's well-being in all scenarios.

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1. Introduction

Grasslands account for approximately 40% of the earth's land surface (White et al., 2000) and provide a variety of ecosystem services (ES) (MEA, 2005). For example, grasslands provide materials for food and clothing by supporting animals such as cattle, sheep, goats, and horses, which provide crucial provisioning services to over 13% of the residents in grassland areas (Lerner et al., 1988; White et al., 2000). Grassland ecosystems also make contributions to regulating services. Grassland carbon sequestration accounts for 34% of the global terrestrial carbon pool (Allen-Diaz et al., 1996; White et al., 2000). In addition, grasslands attract people by beautiful landscapes, native herbivores, diversified plants and birds, and religious and historical sites, and therefore serve as tourist attractions and contribute to tourism development (White et al., 2000; Lindemann-Matthies et al., 2010; Parente and Bovolenta, 2012).

Globally almost half of the grassland has experienced degradation and all three types of ES decreased during the past three decades (White et al., 2000; Hua and Squires, 2015). The provisioning service reductions were particularly severe, as was the reduction in herdsmen's livelihood and well-being (Reyers et al., 2009; Dong et al., 2015). Previous studies found that provisioning services were perceived by all stakeholders as the most important and vulnerable ES (Iniesta-Arandia et al., 2014). Income was found to be an important factor for local people's well-being and was largely influenced by provisioning services (Pereira et al., 2005; Dai et al., 2014). People living in areas with abundant provisioning services often report high levels of well-being (Wang et al., 2018). It is therefore essential to investigate how herdsmen's well-being is be affected by decreases of provisioning services.

However, grassland ecosystems have been understudied through the framework of ES and human well-being, especially for their close relationship with herdsmen's livelihoods and well-being. Since the Millennium Ecosystem Assessment (MEA) proposed the framework of ES and human well-being (2005), many researchers have studied this relationship through case studies. Our search for peer-reviewed case studies on ES and human well-being resulted in 105 publications, however, only seven cases were conducted in grassland and arid/semi-arid ecosystems (Reyers et al., 2009; Oteros-Rozas et al., 2013; Bremer et al., 2014; Dai et al., 2014; Iniesta-Arandia et al., 2014; Dong et al., 2015; Quintas-Soriano et al., 2016). In contrast, there were 37 studies in coastal ecosystem, 15 in agricultural ecosystem, and 14 in forest ecosystem. The relationship between ES and herdsmen's well-being in grassland ecosystem calls for more academic attention particularly when degradation is considered.

This study aims to fill this gap by investigating the association between grassland provisioning services and herdsmen's income/well-being in Xilinhot City, Inner Mongolia Autonomous Region. We employed the Bayesian belief network (BBN) model to explore how uncertainties in precipitation and sheep prices may influence local livelihoods in the future. Specifically, we asked three questions: 1) what are the main factors influencing herdsmen's well-being? 2) what are the possible scenarios for herdsmen's well-being in the future considering uncertainties with the main factors? and 3) considering the uncertainties, what measures can improve herdsmen's well-being? Answers to these questions will not only help us to understand benefits local herdsmen attained from grassland and prepare for future uncertainties, but also contribute to knowledge about the association between provisioning services and local people in grassland ecosystem worldwide.

2. Methods

2.1. Study area

Xilinhot City is located in the center of Inner Mongolia Autonomous Region, China (see Fig. 1). Widely known as the "prairie pearl", Xilinhot City is located in grasslands with traditional nomadic culture and horsemanship tradition. The area of Xilinhot City is 14,785 km^2, of which 93% is pastoral. It has a population of 183,806, of which 28% (50,943) are Mongolian and 14% (25,632) are herdsmen (Xilinhot Statistical Yearbook, 2015). Xilinhot City is located in a semi-arid continental climate. The study area is cold and dry, with an average annual temperature ranging between 0 and 3 °C, and an average annual rainfall of 295 mm. Natural disasters include droughts, sandstorms, snowstorms, and locust plagues (Xilingol Yearbook, 2016).

Since 1990, Xilinhot City has undergone dramatic changes in terms of grassland tenure policy, local economy, herdsmen's livelihoods, and landscapes (Wu et al., 2015; Huang and Jiang, 2017; Li et al., 2018). Before 1980, people in this region were mainly engaged in transhumance, which was influenced by weather conditions and sociopolitical factors (Li et al., 2017). Many herdsmen settled down after grassland and livestock ownership reforms in the 1980s. During the same time period, the grassland deteriorated drastically, particularly after 2000. As a result, both supporting and provisioning services decreased (Dong et al., 2015; Li et al., 2017; Fan et al., 2019).

2.2. Data

2.2.1. Statistical data

Statistical data were obtained from the *Xilinhot Statistical Yearbook* (2000–2015) (Xilinhot Bureau of Statistics, 2015), the *Xilingol Statistical Yearbook* (2010–2018) (Xilingol Bureau of Statistics, 2018), and the *Inner Mongolia Statistical Yearbook* (1985–2015) (Inner Mongolia Bureau of Statistics, 2015). We used growing season precipitation to represent weather conditions. We used livestock inventory, number of animals sold, expenditure on livestock, and net income from livestock to describe the scale of local husbandry (Table 1). Government subsidies, daily life expenditures, and herdsmen's per capita income were used to estimate herdsmen income. Retail price for sheep was obtained from China sheep industry network from 2003 to 2016.

2.2.2. Remote sensing data

We employed the normalized difference vegetation index (NDVI) to describe vegetation cover. We used a series of MODIS Terra 16-day composite images (MOD13A1 Collection 6 product) at a 500 m spatial resolution. We selected 170 NDVI syntheses, including ten images from May to September for each year between 2000 and 2017. Dataset preprocessing included reprojection and format conversion in MRT software and clipping the images to the study area in ArcMap software. Finally, we used the maximum value composite method to composite images of growing season NDVI.

2.2.3. Participatory observation and interviews

Participatory observation is often used to examine relationships between ecosystem services and human well-being (e.g. Pereira et al., 2005; Daw et al., 2015). We conducted participatory observation and semi-structured interviews with key informants in June and July 2017 to understand the relationship between grassland provisioning service and herdsmen's well-being to identify possible influencing factors. The key informants were selected according to how they were involved in local husbandry. We interviewed twelve herdsmen and nine officials. We structured our interview around the following questions: 1) what changed in terms of grasslands and herdsmen's well-being in recent years? 2) what factors are most important to the herdsmen's well-being? and 3) what are the possible scenarios for the herdsmen's future? Each interview lasted approximately 40 min. Information collected from the interviews and observations were included to construct the preliminary modeling framework.

2.2.4. Expert survey

We conducted an expert survey in December 2018 in order to finalize the factors included in the model and their weights (Table 2). The expert

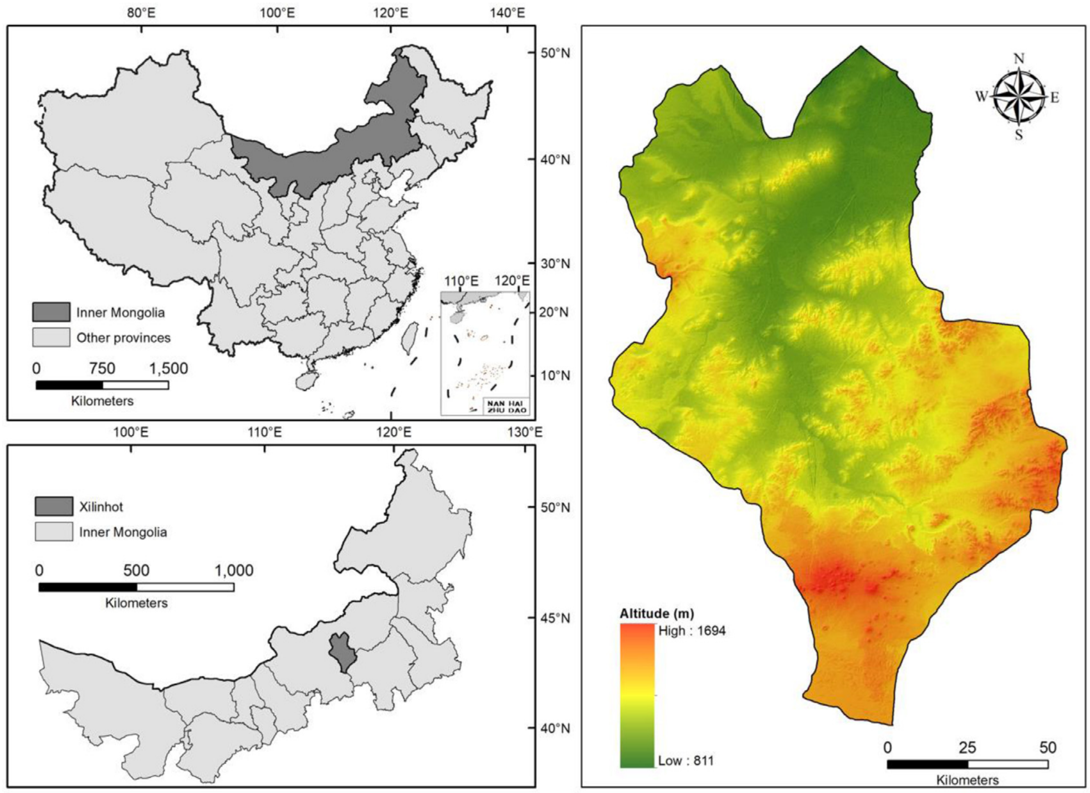


Fig. 1. Study area map.

Table 1
Explanation, source and time period for indicators.

Indicator	Explanation	Period	Data Source
Growing season precipitation	The precipitation between May and September. Representing the climate changes.	1985–2017	Inner Mongolia Statistical Yearbook
The previous year's livestock inventory	Representing the changes in sheep husbandry.	1986–2017	
The number of animal sold		1985–2017	
Expenditure on livestock	Expenditures on sheep husbandry, such as fodder, disease prevention, machinery and so on.	2001–2017	Xilinhot Statistical Yearbook
Net income from livestock	Income excluding the expenditure on sheep husbandry.		
Government subsidy	Income from governments for preventing disasters and improving herdsmen's wellbeing.		
Expenditures of daily life	Expenditure on food, clothes, electronic products and so on.		
Herdsmen's per capita net income	Herdsmen's income excluding expenditure of daily life.	1985–2017	Inner Mongolia Statistical Yearbook Xilingol Statistical Yearbook
Retail price of mutton	Representing the sheep price changes.	2003–2017	China Sheep Industry Net

Table 2
Sample questions from the expert survey.

Topic	Question
Well-being	This study considered herdsmen's wellbeing based on income and security. Please set up weight coefficient of each factor for herdsmen's wellbeing (1–10).
	What is the possible trend of disaster (drought, storm) in Xilinhot in the future?
Income	What do you think are the direct impact factors for herdsmen's income?
	Based on the above question, please set up weight to the main factors for herdsmen's income (1–10).
Number of sheep sold	What do you think are the direct factors for number of sheep sold?
	Based on the above question, please set up weight to the main factors for number of sheep sold (1–10).
	Considering other variables unchanged, how do you think number of sheep sold would change with the increase of vegetation cover?
Choice of livelihood	What do you think are the direct factors for herdsmen's decision of their livelihoods?
	Based on the above question, please set up weight to the main factors for herdsmen's decision of livelihoods (1–10).
	Considering other variables unchanged, how do you think herdsmen's decision of livelihoods would change with the increase of sheep price?

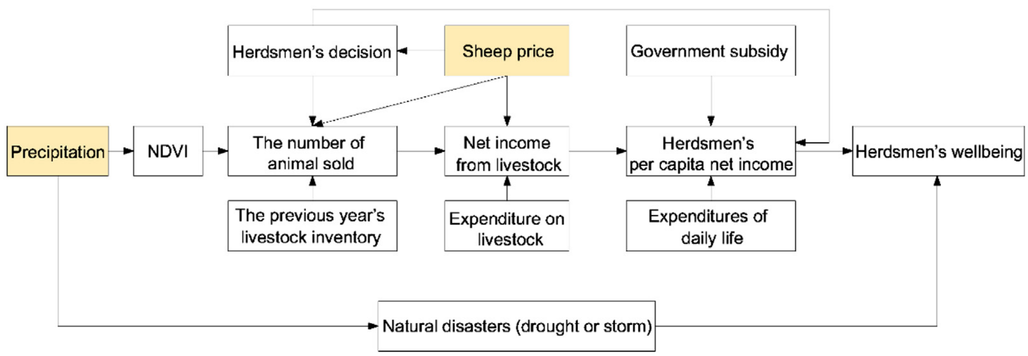


Fig. 2. Influence diagram of herdsmen's well-being
Arrows indicate direction of influence. This diagram was drawn based on participatory observations and interviews with key informants and was used as the initial framework for BBN modeling.

group was composed of five researchers who have studied and have long-standing interests in this field.

2.3. Bayesian belief network (BBN) model building process

The BBN model is a multivariate statistical probabilistic model based on graph and probability theory that has high model transparency (Landuyt et al., 2013). It is a semiquantitative approach and has been widely used in risk assessment, management assessment, decision support and uncertainty analysis (Tremblay et al., 2004; Chen and Pollino, 2012; Gonzalez-Redin et al., 2016; Landuyt et al., 2016; Lohr et al., 2017; Li et al., 2019). The strength of BBN modeling lies in its ability to integrate different types of data from multiple sources and explicitly address uncertainties (Uusitalo, 2007; Aguilera et al., 2011). Some researchers (Landuyt et al., 2013) have used it to describe, analyze, and evaluate ES and their relationship with human well-being.

A BBN model consists of a directed acyclic graph (DAG) and conditional probability tables (CPTs). The DAG represents the dependencies between variables, and the CPT indicates the strength of the causal relations between them (Aguilera et al., 2011). The nodes of the DAG are indicated by directional arrows from a parent node to a child node. The number of node layers, noted as "rank", is often limited to less than five (Marcot et al., 2006., Richards et al., 2013). Each variable contains a few states to describe possible changes. Sensitivity analysis describes how much the beliefs of the target nodes could be influenced by the other nodes in the network. It helped us determine which test would provide the best information about herdsmen's well-being.

We built the herdsmen's well-being model using Netica software. We first drew an influence diagram based on participatory observations and interviews with key informants (Fig. 2). Then, we converted the influence diagram into a DAG and compiled CPTs according to results from the expert survey. The model was adjusted and run with data from 1985 to 2015 followed by a sensitivity analysis (Marcot et al., 2001, 2006).

Our model includes fourteen nodes and five ranks (Fig. 3). The first rank lists factors influencing the number of animals sold, which include the NDVI, whether or not to buy forage (noted as "herdsmen's decision of grass"), previous years' animal inventory, and sheep price. The second rank lists factors influencing net income from livestock, which include number of animals sold, sheep price, and expenditures on livestock. The third rank lists factors influencing herdsmen's per capita net income, which comes from the net income from livestock but is also influenced by choice of livelihood, government subsidies, and daily expenditure. The fourth rank lists factors influencing herdsmen's well-being, which include herdsmen's per capita net income and natural disasters. The last rank is the output variable – the herdsmen's well-being.

2.4. Scenario analysis

We conducted a scenario analysis based on the herdsmen's well-being model in Netica software. Scenario analysis is often used to explore future under uncertainties. Instead of predicting what will happen, scenario analysis presents several possible outcomes to provoke thinking, facilitate discussion, and guide action (Palomo et al., 2011; Oteros-Rozas et al., 2013; Daw et al., 2015; Fischer et al., 2015). Here, we considered two uncertainties: precipitation and sheep price. Our survey showed that these two factors had the most impact on herdsmen's well-being by influencing their major income source –income from sheep husbandry. Precipitation influences the cost of sheep husbandry by influencing winter survival rates, how much forage is needed and the occurrence of disasters. Sheep prices directly influence herdsmen's income from selling sheep. Both factors have dramatically changed over the past three decades and are bearing impacts to different directions from climate change, policies to restore grassland ecosystems, economic globalization and local branding (Zhang et al., 2014; Peng et al., 2018; Zhang et al., 2018; Fang et al., 2019). We considered two possibilities for each factor and developed four scenarios (Fig. 4).

3. Results

3.1. Factors influencing herdsmen's well-being

The compiled BBN model shows the association among the fourteen nodes and weights at five ranks, and the bar chart shows current maximum likelihood states of each variable based on datasets from 1985 to 2015 (Fig. 3).

Our results show that the most important factor for herdsmen's well-being is income, particularly the income from animal husbandry. Table 3 presents the sensitivity analysis results. We ranked the nodes according to their degree of influence on the target nodes. For herdsmen's well-being, variance reduction of beliefs values of herdsmen's per capita net income is the highest (0.1295) among all nodes, which means that herdsmen's per capita net income has the biggest effect on changes in herdsmen's well-being, followed by natural disasters (0.0216) and net income from livestock (0.0063). For herdsmen's per capita net income, the most influential variable is net income from livestock, followed by expenditures of daily life, government subsidies, and sheep prices.

These results indicate that precipitation and sheep prices are the most important factors for herdsmen's income and well-being. It is worth noting that alternative income sources and government subsidies were also important for herdsmen's well-being. The herdsmen's choice of livelihood does not have direct links to the number of animals sold or the net income from livestock. However, it does have an important impact based on the results of the sensitivity analysis. Government subsidies

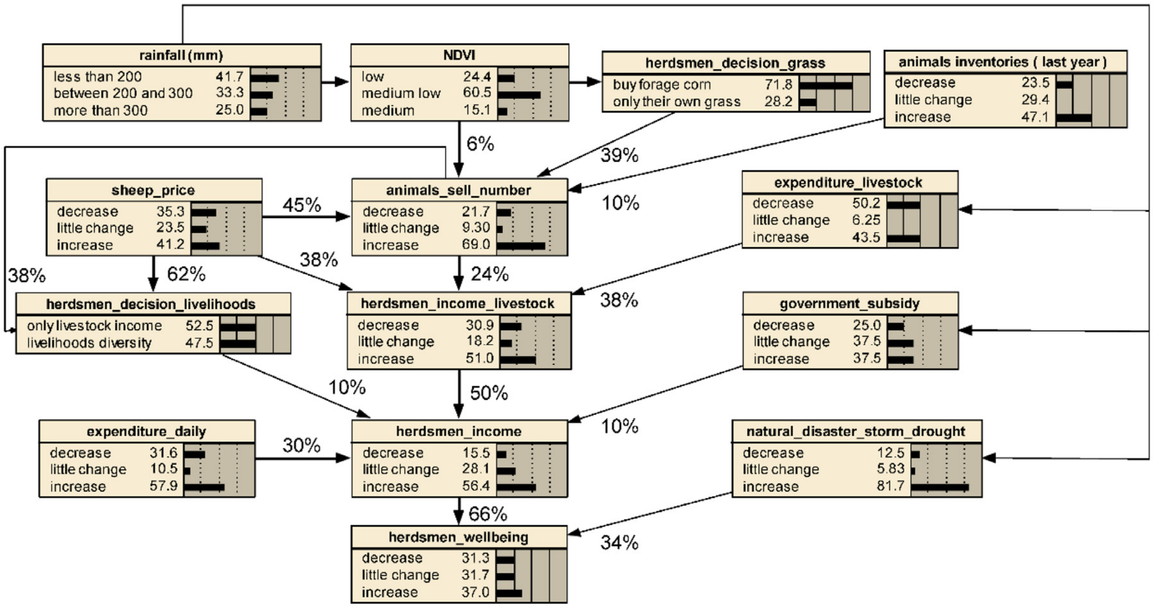
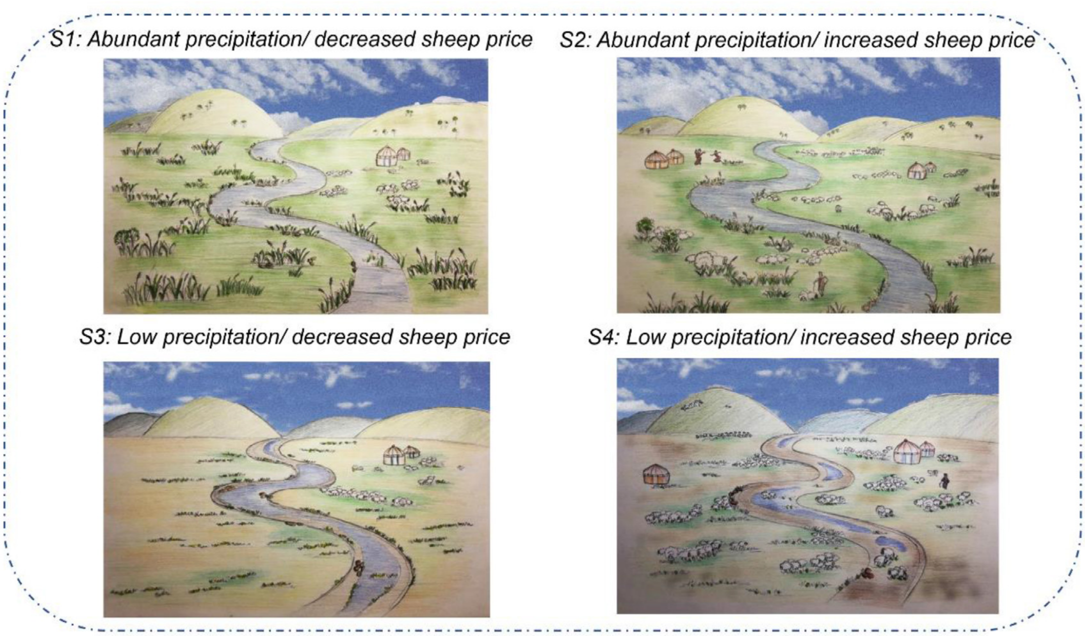


Fig. 3. BBN model for the relationship between grassland output and herdsmen's well-being
Arrows indicate direction of influence. Percents indicate weights for each parent node. Each probability table lists the likelihoods to increase, decrease or barely change for the value of the variable.



Probabilities to increase for selected indicators in the four scenarios (%)

Indicator	1985-2015	S1	S2	S3	S4
NDVI	60.5	71.4	71.4	53.8	53.8
Number of sold animal	69.0	63.4	74.4	63.2	74.2
Net income from husbandry	51.0	37.7	65.9	36.1	64.3
Diversified livelihoods	47.5	61.1	35.5	61.2	35.3
Government subsidy	37.5	30.0	30.0	53.0	53.0
Net income	56.4	53.4	59.5	54.2	60.2
Herdsmen's well-being	37.0	37.1	39.3	34.6	36.8

Fig. 4. Four scenarios and likelihoods of change for selected indicators
Numbers in the table indicate the likelihoods for the indicator to increase under each scenario.

Table 3
Sensitivity analysis results of the BBN model.

Ranking	The number of animal sold	Net income from livestock	Herdsmen's per capita net income	Herdsmen's wellbeing
1	Sheep price	Sheep price	Net income from livestock (0.0469)	Herdsmen's per capita net income (0.1295)
2	Herdsmen decision of grass	Expenditure on livestock	Expenditures of daily life (0.0137)	Natural disasters (0.0216)
3	Herdsmen choice of livelihood	The number of animal sold	Government subsidy (0.0027)	Net income from livestock (0.0063)
4	The previous year's livestock inventory	Herdsmen choice of livelihood	Sheep price (0.0022)	Expenditures of daily life
5	NDVI	Precipitation	Expenditure on livestock	Precipitation (0.0019)
6			The number of animal sold	Sheep price
7			Herdsmen choice of livelihood	Expenditure on livestock
8				Government subsidy

Note: The Numbers in brackets represent the corresponding Variance Reduction of Beliefs values according to the sensitivity analysis results.

Table 4
State-beliefs of variables in four scenarios.

Variable	States	Initial State- beliefs	Scenario 1-Good weather; sheep price↓	Scenario 2-Good weather; sheep price↑	Scenario 3-Bad weather; sheep price↓	Scenario 4-Bad weather; sheep price↑
Expenditure on livestock	↓	50.2	52.5	52.5	42.5	42.5
	↑	43.5	42.5	42.5	52.5	52.5
The number of animal sold	↓	21.7	29.8	14.3	30.5	15.0
	→	9.3	6.7	11.2	6.3	10.8
	↑	69.0	63.4	74.4	63.2	74.2
Net income from Livestock	↓	30.9	42.9	18.0	44.5	19.6
	→	18.2	19.5	16.0	19.5	16.0
	↑	51.0	**37.7**	**65.9**	**36.1**	64.3
Herdsmen choice of livelihood	diversity	47.5	**61.1**	35.5	61.2	35.3
	only livestock	52.5	38.9	**64.7**	38.8	64.7
Government subsidy	↓	25.0	17.0	17.0	17.0	17.0
	→	37.5	53.0	53.0	30.0	30.0
	↑	37.5	30.0	30.0	**53.0**	53.0
Herdsmen's income	↓	15.5	16.6	14.5	16.1	13.9
	→	28.1	29.9	26.1	29.7	25.8
	↑	**56.4**	**53.4**	**59.5**	**54.2**	**60.2**
Natural disasters (storm, drought)	↓	12.5	20.0	20.0	5.0	5.0
	→	5.8	0.0	0.0	5.0	5.0
	↑	81.7	80.0	80.0	**90.0**	90.0
Herdsmen's wellbeing	↓	31.3	31.6	30.1	33.4	31.9
	→	31.7	31.3	30.7	32.0	31.4
	↑	**37.0**	**37.1**	**39.3**	**34.6**	**36.8**

are also an important factor in herdsmen's per capita net income and rank third in the sensitivity analysis (Table 3).

3.2. Scenarios for the herdsmen's future

We developed four scenarios by entering precipitation (200–300 mm and less than 200 mm) and sheep prices (decreasing vs. increasing) in the BBN model (Table 4). It worth noting that BBN results represented likelihoods that the values of variables will increase. We compared likelihoods from each scenario with the results from 1985 to 2015 (referred as "past" hereafter). These four scenarios are graphically summarized in Fig. 4.

Scenario 1 (S1) : Abundant precipitation/decreased sheep prices

In this scenario, precipitation continues to be abundant (200–300 mm), and sheep prices decrease. Results showed that vegetation cover is more likely to increase, and the likelihood of disasters and government subsidies (for disasters) are the same as in the past. The number of animals sold and the net income from livestock are less likely to increase, and herdsmen are more likely to look for additional sources of income. Compared with the past, the likelihood to increase their income is reduced 56.4% vs. 53.4%, respectively, but the likelihood to improve their well-being increases slightly 37.0% vs. 37.1%, respectively. The likelihood to increase income in S1 is the lowest of all the four scenarios.

Scenario 2 (S2): Abundant precipitation/increased sheep price

In this scenario, precipitation continues to be abundant (200–300 mm), and sheep prices increase. Results show that vegetation cover is more likely to increase, and the likelihood of disasters and government subsidies (for disasters) are the same as past. The number of animals sold and the net income from livestock are more likely to increase. Compared with the past, the likelihoods increase for improving income (56.4% vs. 59.4%) and well-being (37.0% vs. 39.3%). The likelihood of improving well-being is the highest among all the scenarios.

Scenario 3 (S3) : Low precipitation/decreased sheep prices

In this scenario, precipitation reduces to less than 200 mm, and sheep prices decrease. Results showed that vegetation cover is less likely to increase, and disasters are more likely to happen. Therefore, both expenditure on forage and government subsidies for disasters are more likely to increase. The number of animals sold and net income from livestock is less likely to increase and herdsmen are more likely to look for additional income sources. Compared with the past, the likelihoods of improving fall for both income (56.4% vs. 54.2%) and well-being (37.0% vs. 34.6%). The likelihood of improving well-being improvement in S3 is the lowest of all the scenarios.

Scenario 4 (S4) : Low precipitation/increased sheep prices

In this scenario, precipitation is reduced to less than 200 mm, and sheep prices increase. Results show that vegetation cover is less likely to increase and disasters are more likely to happen. Therefore, both expenditure on fodder and government subsidies for disasters are more likely to increase. Despite the reduction of precipitation, the number of animals sold is more likely to increase with the increased sheep price as does the net income from livestock. Compared with the past, income is more likely to increase (56.4% vs. 60.2%), but well-being is less likely to improve (37.0% vs. 36.8%). The likelihood of increased incomes in S4 is the highest among all scenarios.

4. Discussion

4.1. Divergence between income and well-being

Results from the four scenarios reveal a considerable divergence between income and well-being. Although S4 generated the highest likelihood of increased incomes, improved well-being only ranked the third out of the four scenarios. Additionally, S1 had the lowest likelihood of increased incomes, but the chance to improve well-being ranked the second. While income is often reported as the most important well-being factor (Wang et al., 2018), they are not completely consistent based on our findings. Vegetation cover and occurrence of disasters also play an important role in herdsmen's well-being.

4.2. Improving herdsmen's well-being under all conditions

Our findings provide clues on ways to improve herdsmen's well-being given the uncertainties of precipitation and sheep prices. First, alternative income sources have been widely discussed as an effective way to increase herdsmen's income and improve their well-being. Tourism is an important cultural service provided by the grasslands (Quintas-Soriano et al., 2016) as well as a promising industry to bring cash to the local population (Dong et al., 2015). Because of the beautiful grassland landscapes and traditional nomadic cultures, Xilinhot City has great tourism potential. The number of tourist visits increased from 0.62 million in 2007 to 4.0 million in 2015, with tourism revenue increasing nearly 13 times during that period (Xilinhot Statistical Yearbook, 2015, 2018). Involving local herdsmen in tourism could provide an alternative income source and increase their resilience to the uncertainties of precipitation and sheep prices. It is worth noting that tourism also has negative impacts, including adverse effect on plant-soil system of grasslands (Feng et al., 2019), and potential interference with herdsmen's traditional lifestyle (Rongna and Sun, 2019). Paying attention to environmental protection and synergizing livelihoods will help to promote the sustainable development of grassland tourism.

Second, our results suggest that government subsidies constitute an important income source for herdsmen when disasters occur. These subsidies typically come from central and local governments and are granted on a case by case basis. We recommend promoting commercial insurance to provide a more stable financial assistance during disasters, which will improve herdsmen's resilience and their well-being.

Last, as our results show, sheep prices play an important role in determining herdsmen's income. However, individual herdsmen do not have a voice in this matter and are often hurt by price fluctuations. Previous studies suggested the importance of capacity building and product marketing (Bremer et al., 2014), which shed light particularly in this case. For example, branding local lamb with grassland icon could potentially help to stabilize sheep prices.

4.3. Limitations and uncertainties

An important limitation is that BBN modeling is unidirectional and unable to incorporate feedback loops (Landuyt et al., 2013). Our model is therefore missing some connections among the variables. For example, after herdsmen decide the number of sheep according to precipitation and sheep prices, the amount of sheep affects the vegetation cover and likelihood of future disasters. Such feedbacks were not considered in our model and scenario analysis. Moreover, this study is limited by the lack of data, particularly some indicators in the early years of the analysis.

5. Conclusions

This study investigated the association between grassland provisioning services, herdsmen's income, and their well-being between 1985 and 2015 using BBN modeling. We found that both herdsmen's income and well-being improved during the past three decades. The results suggest that income is the most important factor (0.1295) for herdsmen's well-being, which is highly sensitive to sheep prices and precipitation. Scenario analysis based on the uncertainties of sheep prices and precipitation revealed a divergence between income and well-being. While herdsmen's income is most likely to increase with low precipitation and increased sheep prices, their well-being is most likely to improve with abundant precipitation and increased sheep prices. We propose three suggestions to improve herdsmen's well-being in all conditions: 1) developing alternative income sources such as tourism; 2) employing commercial insurance to reduce dependence on government subsidies; and 3) branding local lamb to alleviate price fluctuations.

Declaration of Competing Interest

This manuscript is an original work. It has not been published previously and is not under consideration for publication elsewhere. We have no conflict of interest to declare and are willing to accept responsibility for the contents. We look forward to hearing from you at your earliest convenience.

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References

Aguilera, P., Fernandez, A., Fernandez, R., Rumi, R., Salmeron, A., 2011. Bayesian networks in environmental modelling. Environ. Model. Softw. 26 (12), 1376–1388.
Allen-Diaz, B., Chapin, F., Díaz, S., Howden, S., Puigdefábregas, J., Stafford Smith, M., 1996. Rangelands in a changing climate: Impacts, adaptations, and mitigation. In: Watson, R., Zinyowera, M., Moss, R., Dokken, D. (Eds.), Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Cambridge University Press, Cambridge, pp. 131–158.
Bremer, L., Farley, K., Lopez-Carr, D., Romero, J., 2014. Conservation and livelihood outcomes of payment for ecosystem services in the Ecuadorian Andes: What is the potential for 'win-win'? Ecosyst. Serv. 8, 148–165.
Chen, S., Pollino, C., 2012. Good practice in Bayesian network modelling. Environ. Model. Softw. 37, 134–145.
Dai, G., Ulgiati, S., Zhang, Y., Yu, B., Kang, M., Jin, Y., Dong, X., Zhang, X., 2014. The false promises of coal exploitation: How mining affects herdsmen well-being in the grassland ecosystems of Inner Mongolia. Energy Policy 67, 146–153.
Daw, T., Coulthard, S., Cheung, W., Brown, K., Abunge, C., Galafassi, D., Peterson, G., McClanahan, T., Omukoto, J., Munyi, L., 2015. Evaluating taboo trade-offs in ecosystems services and human well-being. Proc. Natl. Acad. Sci. U.S.A. 112 (22), 6949–6954.
Dong, X., Dai, G., Ulgiati, S., Na, R., Zhang, X., Kang, M., Wang, X., 2015. On the relationship between economic development, environmental integrity and well-being: The point of view of herdsmen in Northern China Grassland. PLoS ONE 10 (9), 23.
Fan, F., Liang, C., Tang, Y., Harker-Schuch, I., Porter, J., 2019. Effects and relationships of grazing intensity on multiple ecosystem services in the Inner Mongolian steppe. Sci. Total Environ. 675, 642–650.
Fang, X., Guo, X., Zhang, C., Shao, H., Zhu, S., Li, Z., Feng, X., He, B., 2019. Contributions of climate change to the terrestrial carbon stock of the arid region of China: A multi-dataset analysis. Sci. Total Environ. 668, 631–644.
Feng, L., Gan, M., Tian, F., 2019. Effects of grassland tourism on alpine meadow community and soil properties in the Qinghai-Tibetan Plateau. Pol. J. Environ. Stud. 28 (6), 4147–4152.
Fischer, J., Horcea-Milcu, A., Hartel, T., Hanspach, J., Mikulcak, F., 2015. The Future of People and Nature in Southern Transylvania. Pensoft Publishers, Bulgaria.
Gonzalez-Redin, J., Luque, S., Poggio, L., Smith, R., Gimona, A., 2016. Spatial Bayesian belief networks as a planning decision tool for mapping ecosystem services trade-offs on forested landscapes. Environ. Res. 144, 15–26.
Hua, L., Squires, V., 2015. Managing China's pastoral lands: Current problems and future prospects. Land Use Policy 43, 129–137.

Huang, G., Jiang, Y., 2017. Urbanization and socioeconomic development in Inner Mongolia in 2000 and 2010: A GIS analysis. Sustainability 9 (2), 11.
Iniesta-Arandia, I., Garcia-Llorente, M., Aguilera, P., Montes, C., Martin-Lopez, B., 2014. Socio-cultural valuation of ecosystem services: Uncovering the links between values, drivers of change, and human well-being. Ecol. Econ. 108, 36–48.
Inner Mongolia Bureau of Statistics, 2015. Inner Mongolia Statistical Yearbook (1985–2015).
Landuyt, D., Broekx, S., D'Hondt, R., Engelen, G., Aertsens, J., Goethals, P., 2013. A review of Bayesian belief networks in ecosystem service modelling. Environ. Model. Softw. 46, 1–11.
Landuyt, D., Broekx, S., Engelen, G., Uljee, I., Van der Meulen, M., Goethals, P.L.M., 2016. The importance of uncertainties in scenario analyses - A study on future ecosystem service delivery in Flanders. Sci. Total Environ. 553, 504–518.
Lerner, J., Matthews, E., Fung, I., 1988. Methane emission from animals: A global high-resolution data base. Global Biogeochem. Cycles 2 (2), 139–156.
Li, A., Chen, S., Zhang, X., Huang, J., 2017a. Political pressures increased vulnerability to climate hazards for nomadic livestock in Inner Mongolia, China. Sci. Rep. 7, 12.
Li, J., Song, G., Semakula, H., Zhang, S., 2019. Climatic burden of eating at home against away-from-home: A novel Bayesian Belief Network model for the mechanism of eating-out in urban China. Sci. Total Environ. 650, 224–232.
Li, Z., Bagan, H., Yamagata, Y., 2018. Analysis of spatiotemporal land cover changes in Inner Mongolia using self-organizing map neural network and grid cells method. Sci. Total Environ. 636, 1180–1191.
Li, Q., Zhang, X., Liu, Q., Liu, Y., Ding, Y., Zhang, Q., 2017. Impact of land use intensity on ecosystem services: An example from the agro-pastoral ecotone of Central Inner Mongolia. Sustainability 9 (6), 11.
Lindemann-Matthies, P., Junge, X., Matthies, D., 2010. The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. Biol. Conserv. 143 (1), 195–202.
Lohr, C., Wenger, A., Woodberry, O., Pressey, R., Morris, K., 2017. Predicting island biosecurity risk from introduced fauna using Bayesian belief networks. Sci. Total Environ. 601, 1173–1181.
Marcot, B., Holthausen, R., Raphael, M., Rowland, M., Wisdom, M., 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. For. Ecol. Manag. 153 (1–3), 29–42.
Marcot, B., Steventon, J., Sutherland, G., McCann, R., 2006. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. Can. J. For. Res. 36 (12), 3063–3074.
MEA, 2005. Millennium Ecosystem Assessment: Ecosystems and Human Well-Being. Volume 1 Current State and Trends. Island Press, Washington, D.C.
Oteros-Rozas, E., Martin-Lopez, B., Lopez, C., Palomo, I., Gonzalez, J., 2013. Envisioning the future of transhumant pastoralism through participatory scenario planning: A case study in Spain. Rangel. J. 35 (3), 251–272.
Palomo, I., Martin-Lopez, B., Lopez-Santiago, C., Montes, C., 2011. Participatory scenario planning for protected areas management under the ecosystem services framework: The donana social-ecological system in southwestern Spain. Ecol. Soc. 16 (1), 33.
Parente, G., Bovolenta, S., 2012. The role of grassland in rural tourism and recreation in Europe. In: Proceedings of the 24th General Meeting of the European-Grassland-Federation. Lublin.
Peng, Y., Long, S., Ma, J., Song, J., Liu, Z., 2018. Temporal-spatial variability in correlations of drought and flood during recent 500 years in Inner Mongolia, China. Sci. Total Environ. 633, 484–491.
Pereira, E., Queiroz, C., Pereira, H., Vicente, L., 2005. Ecosystem services and human well-being: A participatory study in a mountain community in Portugal. Ecol. Soc. 10 (2), 23.
Quintas-Soriano, C., Castro, A., Castro, H., Garcia-Llorente, M., 2016. Impacts of land use change on ecosystem services and implications for human well-being in Spanish drylands. Land Use Policy 54, 534–548.
Reyers, B., O'Farrell, P., Cowling, R., Egoh, B., Le Maitre, D., Vlok, J., 2009. Ecosystem services, land-cover change, and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. Ecol. Soc. 14 (1), 38.
Richards, R., Sano, M., Roiko, A., Carter, R., Bussey, M., Matthews, J., Smith, T., 2013. Bayesian belief modeling of climate change impacts for informing regional adaptation options. Environ. Model. Softw. 44, 113–121.
Rongna, A., Sun, J., 2019. Integration and sustainability of tourism and traditional livelihood: A rhythmanalysis. J. Sustain. Tour. 28 (3), 455–474.
Tremblay, J., Hester, A., McLeod, J., Huot, J., 2004. Choice and development of decision support tools for the sustainable management of deer-forest systems. For. Ecol. Manag. 191 (1–3), 1–16.
Uusitalo, L., 2007. Advantages and challenges of Bayesian networks in environmental modelling. Ecol. Model. 203 (3–4), 312–318.
Wang, Y., Liu, G., Guo, E., 2018. Spatial distribution and temporal variation of drought in Inner Mongolia during 1901-2014 using standardized precipitation evapotranspiration index. Sci. Total Environ. 654, 850–862.
White, R., Murray, S., Rohweder, M., 2000. Pilot Analysis of Global Ecosystems: Grassland Ecosystems. World Resources Institute, Washington D.C..
Wu, J., Zhang, Q., Li, A., Liang, C., 2015. Historical landscape dynamics of Inner Mongolia: Patterns, drivers, and impacts. Landsc. Ecol. 30 (9), 1579–1598.
Xilingol Bureau of Statistics, 2018. Xilingol Statistical Yearbook (2010–2018).
Xilinhot Bureau of Statistics, 2015. Xilinhot Statistical Yearbook (2000–2015).
Xilinhot Bureau of Statistics, 2015. Xilinhot Yearbook.
Xilingol Bureau of Statistics, 2016. Xilingol Yearbook.
Zhang, J., Huntsinger, L., Li, Y., Li, W., 2018. Is microcredit a form of risk for pastoral households of Inner Mongolia's semiarid rangelands? Rangel. Ecol. Manag. 71 (3), 382–388.
Zhang, Q., Ding, Y., Ma, W., Kang, S., Li, X., Niu, J., Hou, X., Li, X., Sarula, 2014. Grazing primarily drives the relative abundance change of C-4 plants in the typical steppe grasslands across households at a regional scale. Rangel. J. 36 (6), 565–572.