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Authors: Yunjie, Wei, Lin, Zhen, and Bingzhen, Du

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Effects of Grassland Restoration Approaches in Different Major Function-oriented Zones of the Headwater Region of the Yellow River in China

WEI Yunjie[1,2], ZHEN Lin[1,2,*], DU Bingzhen[3]

1. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
2. University of Chinese Academy of Sciences, Beijing 100049, China;
3. Wageningen University and Research, Wageningen 6700 AA, The Netherlands

Abstract: Given the high alpine grassland coverage and intensive animal grazing activity, the ecosystem and livelihood of the herders are extremely vulnerable in the headwater region of the Yellow River. A series of programs have been implemented by the Chinese government to restore degraded grasslands in this region, and major function-oriented zones (MFOZs) applied in 2014, have divided the region into three zones, i.e., the development prioritized, restricted, and prohibited zones, based on environmental carrying capacity, as well as the utilization intensity of grassland. This study identified various restoration approaches adopted in different MFOZs, and assessed the effects of the approaches in order to determine the most effective approaches. We collected 195 questionnaires from herders to analyze the effects of the various restoration approaches, and additional remote sensing and statistical data were also used for the analysis. Four distinct differences in the ecological and socioeconomic characteristics were found in three MFOZs. (1) Five technologies were applied in the study areas. (2) The grassland recovery rate was higher in development prioritized zones than in restricted and prohibited zones during 2000 and 2016, and especially high and very high coverage grasslands increased in the areas where crop-forage cultivation and grass seeding dominated in the prioritized zones. (3) The net income of households in the development prioritized zone was the best of all three zones. (4) The degree of awareness and willingness of herders to restore grassland was more positive in development prioritized zones than in restricted zones, where more herders adopted approaches with a combination of enclosure + deratization + crop-forage cultivation + warm shed. Based on these findings, it is recommended that decision-makers need to increase their efforts to narrow the gap of willingness and behavior between herders and other stakeholders, such as researchers and grassland administrators, in order to ensure grassland sustainability in the MFOZs. It is also beneficial to understand the effects of restoration on the ecological carrying capacities in different zones depending on the different development goals.

Key words: major function-oriented zones (MFOZs); ecological restoration approaches; effect evaluation; stakeholders; headwater region of the Yellow River

1 Introduction

The headwater region of the Yellow River is one the of the most important water source and ecological barrier regions, since it is part of the Three Rivers Headwater Region (the Yangtze, Yellow and Mekong Rivers) which is located in the north eastern part of the Qinghai-Tibet Plateau and in the upper part of the Yellow River. The ecological environment in this region is fragile and extremely vulnerable, and it

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First author: WEI Yunjie, E-mail:weiyj.17b@igsnrr.ac.cn
***Corresponding author:** ZHEN Lin, E-mail: zhenl@igsnrr.ac.cn

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provides the ecological security barrier functions of the local and surrounding areas, such as water and soil conservation (Yao et al., 2012), biodiversity conservation (Zhuang et al., 2010), and carbon source/sink capacity (Piao et al., 2009; Li et al., 2013), due to its special alpine and arid climate conditions (Sun et al., 2012). On the one hand, the area of grassland accounts for more than 65%, and the livelihoods of herders rely heavily on the pastures. On the other hand, the local herders are seldom directly involved in ecological environmental protection and decision-making (Shen and Tan, 2012).

The core part of the Yellow River headwater region lies in Qinghai Province. The General Planning on Ecological Protection and Construction in Qinghai Sanjiangyuan Nature Reserve was approved by the State Council of China in order to solve several problems, such as the cutoff of the Yellow River and alpine grassland degradation. The second phase (2013-2020) of the project covered 22 counties in Qinghai Province and the area affected by the project expanded to 395 000 km^2 from only 152300 km^2 in the first phase (2005-2010). To achieve the goal of the plan, 22 programs have been designed and implemented, including the Rodent Control, Grain for Green, 'Black Soil Patch' Degraded Grassland Control, Ecological Migration, and Grassland Fire Prevention Programs. Due to the continuing overexploitation of natural resources and deterioration of the ecological environment following the implementation of ecological restoration technologies (Zhen et al., 2017; Zhen and Xie, 2019), researchers are gradually realizing the importance of sustainable development and environmental protection (Lu, 2009; Ma et al., 2016). They recognize that operating within the sustainable ecological carrying capacity was the basis for sustainable development of the regional economy, society, resources and the environment, and that assessment of grassland restoration will be significant to the final goal of coordinated regional development (Ma et al., 2016).

The recent studies in the headwater region of the Yellow River have shown that: the overall degradation trend of the ecosystem has not been fundamentally contained, and there are still large areas of degraded grassland, desertification land and rodents and pests (Kammer et al., 2013; Liu et al., 2016); overloading and pastoralism still exist, due to the weak infrastructure of animal husbandry and traditional grazing (Foggin, 2008; Wang et al, 2016); and natural and technical constraints remain serious (Zhen et al., 2018). However, there is still a lack of sufficient studies on the effects of the specific restoration approaches adopted in the environmental policies which have been implemented in different major function-oriented zones (MFOZs) under different goals (Fan et al., 2010). In the process of ecosystem conservation and restoration in the headwater region of the Yellow River, MFOZs have played an important role in protection and governance by zoning and classification. The conceptual goal of MFOZs is to determine different regions based on the natural conditions, the laws of nature and various development modes. It is clearly beneficial to reverse the trend of ecological degradation and achieve sustainable development in the different MFOZs. Therefore, the evaluation of ecological technology based on the MFOZs can provide the scientific basis for carrying out ecological governance and for proposing a coordinated development scheme for the ecological industry.

The objectives of this study are to identify the major restoration approaches adopted by the representative households in the headwater region of the Yellow River, to assess the impacts of restoration programs and approaches on vegetation coverage, and to analyze the socio-economic conditions of the households in different MFOZs. The findings are expected to provide a basis for proposing the most effective restoration approaches and also the evidence for alpine grassland restoration and sustainable regional development.

2 Materials and methods

2.1 Study area

The Yellow River is the second largest river in China. The headwater region of the Yellow River contributes approximately 35% of the multi-year mean of the total annual runoff of the Yellow River Watershed, and plays an important role in the overall stability of the river's water supply and ecosystem conservation (Zhou and Huang, 2012; Tian et al, 2015). This study covers four counties in the northeast of the Qinghai-Tibet Plateau and headwater region of the Yellow River, including Maqin, Jiuzhi and Maduo in Guoluo Autonomous Prefecture, and Guinan in Hainan Autonomous Prefecture. These four counties lie in three MFOZs with different natural conditions (elevation) and development goals. The average elevation is 4003 m above sea level (asl) and ranges between 2204 m and 6100 m (Fig. 1). In 2015, 72.3% (3.887×10^6 ha) of the study area was covered by alpine grasslands, dominated by alpine meadow and mountain steppe (Table 1). The vegetation growing season is from the end of March to August (Zhang et al., 2015). The study area is characterized by alpine, windy and drought conditions, with an annual average temperature ranging from –5.6 ℃ to 7.8 ℃ in Guoluo and Hainan, and the annual precipitation is between 262 and 773 mm. About 90% of the total population in the three counties in Guoluo and 76% of that in the one county of Hainan belong to Tibetan ethnic group. The rural population accounts for about 75%. There are three kinds of MFOZs in Qinghai Province, with different development goals (DRCQP, 2014).

- Development prioritized zone: Establish a characteristic agricultural and animal husbandry industrialization base.

- Restricted zone: Establish an important ecological security barrier in the country, and actively develop ecological animal husbandry, ecological tourism and ethnic handicrafts

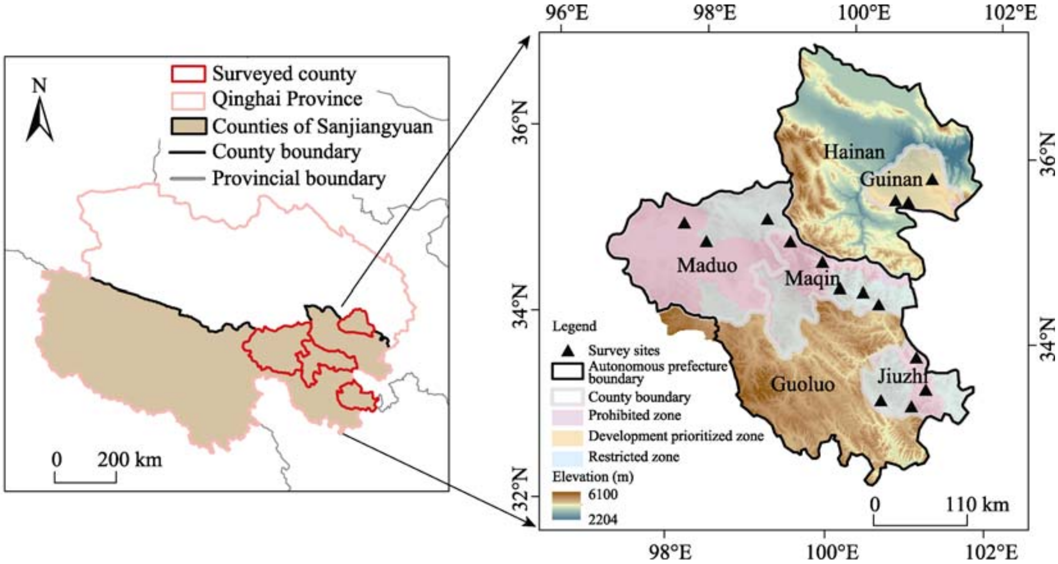


Fig. 1 Location of study area

Table 1 Basic information regarding the study area

Major function-oriented zones	County	Towns/villages	Area proportion (%)	Average elevation (m)	Major ecosystem type
Development prioritized zone	Guinan	Taxiu, Senduo, Guomaying	11.8	3376	Mountain steppe Alpine meadow
Restricted zone	Maqin	Dawu, Xiadawu, Dongqinggou	38.3	4279	Alpine meadow Steppe Alpine swamp
	Maduo	Huashixia			
	Jiuzhi	Mentang, Baiyu			
Prohibited zones	Maqin	Xueshan	49.9	4355	Alpine meadow Mountain steppe
	Maduo	Zhalinghu, Machali			
	Jiuzhi	Suohurima, Waeryi			
Total or mean	4	14	100	4003	–

on the plateau.

- Prohibited zone: Protect important areas of natural reserve, historical and cultural resources, and strictly control human interference.

2.2 Data and method

2.2.1 Household surveys

Following an initial survey of the literature and discussions with institutional stakeholders, and considering the difficulty in acquiring statistical data for the nomadic area, it was deemed necessary to employ a household survey to collect primary data. Prior to the formal surveys, we conducted an informal, preliminary survey via individual interviews and group discussions with herders and key informants to test our questions, guide the development of the formal questionnaire, and ultimately increase the validity of the results.

We used a stratified random sampling method (Weber and Tiwari, 1992) to select the villages in our study. In this process, we specifically included villages that differed in terms of grassland type; elevation; adoption of restoration approaches; income level; species and number of animals raised; and the distances from homes to the pastures, to the nearest main road, and to the county center. Accordingly, we selected 32 survey sites in 14 villages from the four counties, which included alpine pastoral and agro-pastoral systems in highlands above 3500 m, average population density ranges from 2 to 10 persons km^{-2}, and distances between households on summer pastures of 5–20 km and sites scattered throughout a large area of the summer pasture. Based on these features, we used occasional random sampling (Weber and Tiwari, 1992) for our survey. Because no obvious pathways led through the villages, we started at one end of the pasture area and walked through the village area until we had spoken with representatives of a sufficient number of households in each village. We asked the head of each household or a family member who was familiar with the household to answer our questions. To ensure correct understanding of the questions, we hired 2–3 local interpreters to translate the questions from Mandarin to Tibetan because over 73% of the respondents did not speak Mandarin. The interviews were conducted in either the houses or tents of the respondents, along the roads, at public meeting places, in grasslands, or at other places. Completion of a questionnaire required about 1–1.5 h, with translation.

Altogether, 195 households were interviewed, with 51 respondents in Maqin County, 43 in Jiuzhi County, 54 in Maduo County, and 47 in Guinan County, which accounted for 67%–74% of the total households in the respective villages. Our surveys were conducted from July to August 2017. The interviews included questions in the following areas: the socioeconomic characteristics of the household, with questions related to the household composition, levels of education, land and livestock owned, income structure, and consumption; major restoration approaches used; effects of the restoration approaches; perception of grassland recovery; and willingness to participate in grassland conservation projects. We primarily used closed-ended questions, but added open-ended questions when there was an opportunity to expand on certain topics during the interview.

The survey data were analyzed using SPSS software (version 19.0). Specifically, we calculated descriptive statistics and used independent-sample t-tests to identify significant differences between groups.

2.2.2 Spatial data collection and processing

For the purpose of analyzing the changes in vegetation coverage, satellite images from different time periods (from 2000 to 2016) were used. MOD13Q1 - MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid NDVI images were downloaded from the NASA website (https://ladsweb.modaps.eosdis.nasa.gov). A shape file of the Qinghai-Tibetan Plateau boundary was obtained from Zhang et al. (2014). Land coverage at a 1 km grid and the county boundary shape file were obtained from Data Center for Resources and Environment of Chinese Academy of Sciences. ENVI and ArcGIS tools were used for data processing and spatial analysis.

We obtained NDVI images during the growing seasons (from the end of March to August) of each year in Qinghai-Tibetan Plateau from Zhang et al. (2015), then generated annual NDVI data with the maximum value composite method after atmospheric correction and geometric correction using ENVI software. Generally, the regional vegetation fraction coverage (fc) is calculated based on NDVI vegetation index and a dimidiate pixel model (Li et al., 2004). Below is the formula for fc calculation:

$$fc = (NDVI - NDVI_{\min}) / (NDVI_{\max} - NDVI_{\min}) \quad (1)$$

where $NDVI$ represents the NDVI value of the pixel; $NDVI_{\min}$ and $NDVI_{\max}$ are two input parameters of the model, representing the NDVI values of pure pixels of barren soil and vegetation, respectively. This study calculated $NDVI_{\min}$ and $NDVI_{\max}$ using lower and upper thresholds in the 5% confidence interval of the NDVI value (Li et al., 2004).

Annual average values of fc for the periods of 2000–2005 and 2011–2016 were calculated using Cell Statistics of ArcGIS, since the average values can better avoid the extreme values in a specific year, and they can represent the vegetation status at the beginning of the time period and current years since the implementation of ecological restoration programs was in 2000. Then, the fc values were further assigned to five classes using Natural Breaks method, which was based on natural groupings inherent in the data. The five classes were named as: I (very low coverage, $fc \leqslant 10\%$), II (low coverage, $10\% < fc \leqslant 30\%$), III (medium coverage, $30\% < fc \leqslant 50\%$), IV (high coverage, $50\% < fc \leqslant 70\%$) and V (very high coverage, $fc > 70\%$).

The vegetation fraction changes from 2000 to 2016 were analyzed using the Raster Calculator of ArcGIS as shown in formula (2):

$$\Delta fc = fc_c - fc_b \quad (2)$$

where Δfc represents the change in the value of vegetation fraction coverage between the beginning stage (fc_b) and the current stage (fc_c). Using the natural breaks method, the results were classified into five levels, namely: significant increase ($\Delta fc > 0.10$), slight increase ($0.01 < \Delta fc \leqslant 0.10$), no change ($-0.01 < \Delta fc \leqslant 0.01$), slight decrease ($-0.10 < \Delta fc \leq -0.01$) and significant decrease ($\Delta fc \leqslant -0.10$).

We also used grassland net primary productivity (NNP) data obtained by using a Carnegie–Ames–Stanford Approach (CASA) model from the Chinese Academy of Sciences.

3 Results

3.1 Grassland restoration approaches in different major function-oriented zones

The household and institution survey identified five ecological restoration technologies that had been adopted in the study areas, i.e., enclosure, grazing prohibition, deratization, grass (perennial herbs) seeding, and crop-forage cultivations (annual herbs) + warm shed. These technologies were combined and applied as five different approaches:

- **Approach A:** Enclosure only, used by 43 households.
- **Approach B:** Grazing prohibition, used by 33 households.
- **Approach C:** A combination of the enclosure and deratization, used by 45 households.
- **Approach D:** A combination of the enclosure + deratization + grass seeding (perennial herbs), used by 35 households.
- **Approach E:** A combination of the enclosure + deratization + crop-forage cultivation + warm shed, used by 39 households.

The top three approaches adopted by herders in the development prioritized zone were Approach E (40.4%), Approach C (25.5%) and Approach D (19.1%). Meanwhile, 76.8% of herders in the restricted zone adopted Approach C (28.0%), Approach A (26.8%) and Approach E (22.0%). In the prohibited zone, herders mostly preferred Approach B (34.8%) and Approach A (24.2%). The households in the development prioritized zone owned the least grassland and earned the highest net income, whereas the households in the prohibited zone had the most grassland and the lowest net income (Table 2). The livelihood of herders was simple and relied on the subsidy of grazing prohibition, because the area of grazing prohibition grassland was large in the prohibited zone. Each household in the development prioritized zone which owned less grassland raised more animals (96.8 Tibetan sheep and 63.4 yak, which was 1.35 and 1.91 times the number of Tibetan sheep and 1.13 and 1.61 times the number of yak in the restricted and prohibited zones, respectively), taking advantage of the low altitude geographical conditions and more often adopting approach E and approach D.

3.2 Differences in ecological effects

The trend analysis showed that the grassland coverage increased overall. Out of five classes of vegetation coverage, IV (high) and V (very high) coverage grassland increased from 58.4% to 60.6%, and I (very low) and II (low) coverage grassland decreased from 24.0% to 21.6% during the same period. The average NPP increased from 449.6 g C m^{-2} yr^{-1} to 499.2 g C m^{-2} yr^{-1}.

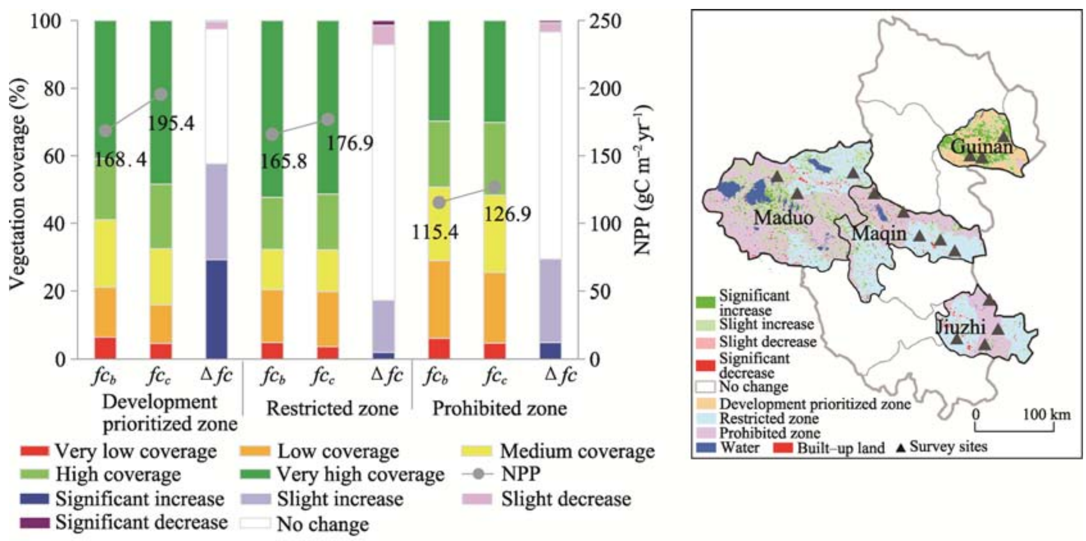
Spatial variations of the vegetation coverage change were observed among the different MFOZs (Fig. 2). The most obvious *fc* and NPP increases (16.0%) were shown in the development prioritized zone, where Approach E was used by over 40% of the households in Guinan. V (very high) and IV (high) coverage grassland increased from 58.9% to 67.6%, and II (low) and I (very low) coverage grassland decreased from 20.8% to 16.0%. In this zone, 40.4% and 19.1% households adopted Approaches E and D, respectively.

In the restricted zone, 54.8% of households adopted Approaches A and C, and 13.4% adopted Approach E. As a result, 1.4% and 5.8% of the vegetation coverage showed significant and slight decreases, whereas only 2.0% and 15.4% showed significant and slight increases, respectively. The NPP value increased by 6.7%, of which, *fc* showed a significant decrease in Baiyu Village in Jiuzhi County, where 100% of herders adopted Approaches A and C.

In the prohibited zone, NPP increased by 10.0%, and 5.0% and 24.4% of the vegetation coverage showed significant

Table 2 Features of households in different MFOZs

Major function-oriented zones	Approach	Household	Household size (persons)	Education level (years)	Area of grassland (ha household^{-1})	Net income (Yuan household^{-1})
Development prioritized zone	A(5), B(2), C(12), D(9), E(19)	47	5.9	5.2	91.7	79970.1
Restricted zone	A(22), B(8), C(23), D(18), E(11)	82	4.9	3.4	412.6	70356.5
Prohibited zones	A(16), B (23), C(10), D(8), E(9)	66	5.2	3.9	699.2	45736.3
Total or mean	–	195	5.3	4.2	401.2	65354.3



(a) Vegetation coverage and NPP in different zones (b) Spatial differences in vegetation coverage

Fig. 2 Vegetation fraction coverage and NPP in different MFOZs and slight increases, while 0.6% and 2.7% showed significant and slight decreases, respectively, especially in Zhalinghu Village in Maduo County. The grassland of 83.3% of the households in Zhalinghu was under grazing prohibition (Approach B).

3.3 Differences in economic effect

We used the income of herder households, which indicated herders' livelihood, to assess the economic effects of the restoration approaches used. The average annual net household income in the study sites was about 65354.3 Yuan household^{-1} yr^{-1} (Table 2), which was higher than the national average rural household net income of 38834.8 Yuan household^{-1} yr^{-1} (NBSC, 2016) and the provincial average of 32763.3 Yuan household^{-1} yr^{-1} (QPBS and NBSSQQ, 2016). Agricultural (selling animals, grazing related subsidies) and non-agricultural (Tibetan medicine, other wages) income accounted for 49.7% and 50.3%, respectively. From the perspective of the income structure, the main sources were ranked as selling animals (19018.1 Yuan household^{-1} yr^{-1}, 29.1% of total) > Tibetan medicine (18037.8, 27.6%) > others (14835.4, 22.7%) > subsidies (13463.0, 20.6%).

In the development prioritized zone, the income categories ranked as selling animals (55.8%) > Tibetan medicine (20.0%) > others (16.3%) > subsidy (8.0%). In this zone, 40.4% and 19.1% of households with less grassland adopted Approaches E & D and they got more income from animal husbandry in Guinan County. The income categories of the restricted zone ranked as Tibetan medicine (45.8%) > selling animals (23.8%) > others (15.8%) > subsidy (14.7%), given that about 54.9% of the households which applied Approach A & C and 22.0% which applied Approach D are living in Dawu Town, Xiadawu and Dongqinggou Village of Maqin County and Mentang and Baiyu Village in Jiuzhi County, where the medicinal plants of cordyceps and fritillaria (*Fritillaria cirrhosa* D. Don) of good quality were produced (Zhang, 2003; Zhao et al., 2018). In the prohibited zone, the income categories ranked as selling animals (39.5%) >Tibetan medicine (28.6%) > subsidy (16.2%) > others (15.8%). In this zone, 34.8% of households adopted Approach B and received much more in subsidies, and each herder whose household was under grazing prohibition and migrated to the town could get 9000 Yuan yr^{-1} starting from 2016 (Fig. 3).

3.4 Differences in social effect

We built the indicator system for evaluating the social effect on restoration according to the household survey data (Table 3). The social effect system included five different indicators: participation level of herders involved, satisfaction with restoration approaches, awareness of restoration and protection, willingness to participate in restoration and protection,

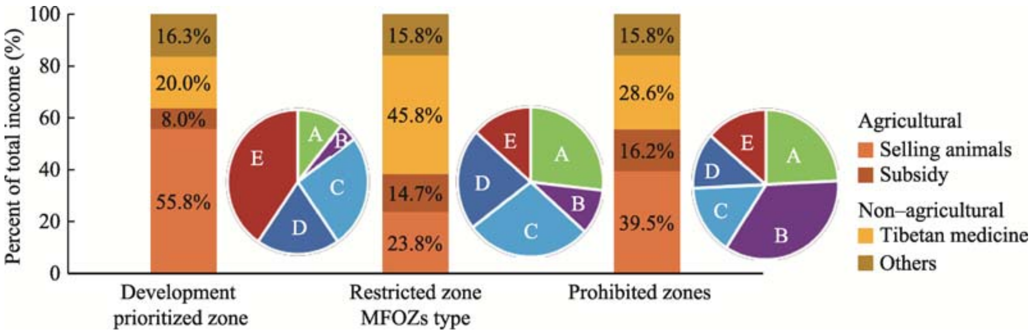


Fig. 3 The structure of herder incomes in different zones

Table 3 Evaluation and score standards of social effect on restoration

Indicator	Score level 1	2	3	4	5
Participation level of herders involved	None	All invested by government	Materials invested by government and self-employment	Self-investment sometimes	Self-mobilization and self-investment
Satisfaction with restoration approaches[a]	Very poor	Slightly poor	Moderate	Slightly well	Very well
Awareness of restoration	No understanding	Less understanding	Moderate understanding	Better understanding	Understanding very well
Willingness to participate in restoration	No willingness	/	Willingness for government investment	/	Willingness for self-investment
Cost of restoration[b] (Yuan household^{-1} yr^{-1})	< 1000	1001–3000	3000–5000	5000–10000	> 10001

[a] The satisfaction indicates the grassland situation with the given restoration approaches.
[b] Cost of restoration by herders includes tools and poison for rodent control, fence construction, grass seeds and hiring workers.

and cost of the restoration approach. The indicator system indicated the behavior and perception of herders for protecting and restoring grassland. The results showed that the overall social effect was the best in the development prioritized zone, where the scores were the highest for four dimensions but not for the awareness of grassland restoration.

Awareness and satisfaction with restoration from herders in the prohibited zone was higher than that in the restricted zone (Fig. 4), because the subsidies and policies of grassland restoration were well publicized and already in practice in the Sanjiangyuan national park of Maduo, i.e. the ecological migration and ecological workers employed from among the herders. The scores for willingness and cost of restoration and participation level of the herders involved ranked as development prioritized zone > restricted zone > prohibited zone, which is the same rank as the net income (79970.1 Yuan household^{-1} > 70356.5 Yuan household^{-1} > 45736.3 Yuan household^{-1}).

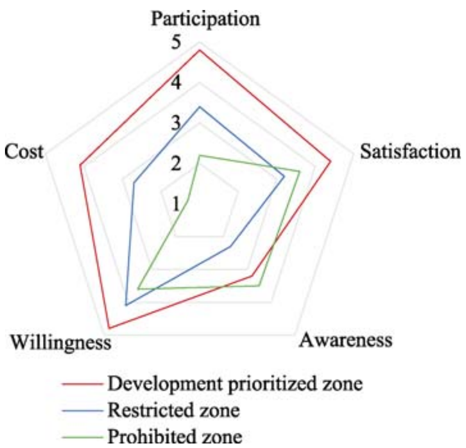


Fig. 4 Social effects on grassland restoration from herders

4 Discussion

This study is significant for understanding the effects of restoration approaches and providing a basis for proposing the effective approaches in different MFOZs. The findings of this study also focused on the following four main issues. First, the results showed that vegetation coverage had an overall increase during 2000-2016, however, it was difficult to quantify the effects of climate change (temperature and precipitation) and human activities (grazing and ecological restoration approaches) on the grassland change. Although the existing studies indicated that climate changes played a dominant role in the interannual trends of vegetation productivity in the alpine ecosystems on Qinghai-Tibetan Plateau (Zhang et al., 2017; Yang et al., 2019), the analysis of temperature and precipitation in this study showed no significant trends and it did not show the contribution of climate change on grassland restoration over the past 16 years (Appendix Fig. S). In the context of the policy of grassland ecological conservation subsidies and awards and pasture–animal balance (Yang et al., 2018), the number of animals in the development prioritized zone had no relationship with the change in vegetation coverage. The reverse of grassland degradation (mutation) was considered as the result of the restoration approach and the program in the short term (Li et al., 2011; Zhang et al., 2017).

Second, research on the social and economic effects on grassland restoration has been less prominent than the research on the ecological effects using remote sensing approaches (Shao et al., 2016; Shao et al., 2017), but the former cannot be ignored. The ecological effects also have links to the social and economic effects, and they work together for the sustainability of ecological restoration programs (Zhen et al., 2014; Yang et al., 2018). For example, the satisfaction of household depends directly on the vegetation coverage and income. Herders moving to the towns or suburbs from the grazing prohibition pasture were far from the grassland, but 9000 Yuan person^{-1} yr^{-1} was far less than the income from the animal husbandry on the pasture. The policy decision makers need to pay attention to this discrepancy and provide more off-grassland employment opportunities based on the knowledge, skills and willingness for sustainable livelihoods of the herders besides just as ecological workers in the national parks (Zhen et al., 2018). There was another significant phenomenon related to identifying how and when the herders were willing to change, i.e., the herders in Guinan didn't adopt the deratization approach for several years like those in Maduo, because Tibetan Buddhism does not allow killing. Now, they have to kill rats on the grassland for better grass yield. We will pay more attention to the guiding role of the monks in grass seeding and deratization, in the context of the coupled human–earth system.

Third, the initial goal of MFOZs focuses on the ecological, resource and environmental carrying capacities. This study can explain the facts of better grassland restoration (combined approaches for providing forge and reducing the pressure of grassland), better grassland carrying capacity (smaller grassland and a larger amount of livestock raised) and relatively better ecological and socio-economic effects in the development prioritized zone. It is beneficial to read just the imbalance of regional development that exists in development intensity and future development potential in different regions (Xue et al., 2017; Yang, 2019).

Last, the combined analysis with remote sensing and household survey data can provide significant information for assessing the ecological and socio-economic effects on grassland restoration. The household survey methods focus on the perceptions, attitudes and willingness of local herders who are experienced in managing grassland and animals (Xu, 2004; Xiao et al., 2017). Various stakeholders, including researchers, managers and companies, will be involved in future studies in order to understand the local needs and the scientific findings. However, data acquisition still has limitations for the number of respondents sampled because there were a long distances (average 5-20 km) between different herder households and the survey needed translators between Chinese mandarin and Tibetan in the study area.

5 Conclusions

Herders applied five approaches to grassland restoration in the study area of the Yellow River headwater region in China. Overall, an increase of vegetation coverage was found from 2000 to 2016. The change in vegetation coverage in the development prioritized zone was the best, and that of the restricted zone was the worst among three zones based on different development goals. The economic and social effects on grassland restoration were quite different in three zones. As with the vegetation coverage, the socio- economic effects of the development prioritized zone were the best out of all three zones. The herder income of the restricted zone was higher than that of the prohibited zone, whereas the awareness and satisfaction scores of grassland restoration of the prohibited zone were higher. Policy makers and grassland managers need to help provide guidance for herders' business behavior according to the specific development goals.

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黄河源区不同主体功能区草地恢复措施效果评价

魏云洁[1,2]，甄　霖[1,2]，杜秉贞[3]

1. 中国科学院地理科学与资源研究所，北京 100101；
2. 中国科学院大学，北京 100049；
3. 瓦格宁根大学，瓦格宁根 6700 AA，荷兰

摘　要：位于青藏高原的黄河源区的高寒草地生态系统和牧民生计都极为脆弱，中国政府已经实施了一系列工程以恢复该区的退化草地。2014 年青海省实施的主体功能区规划，依据资源环境承载能力、现有开发强度和发展潜力将研究区分为重点开发区、限制开发区和禁止开发区。本文旨在识别不同主体功能区采用的草地恢复措施并评估其生态和社会经济影响，以筛选有效的恢复措施。基于 195 份牧户调查问卷和遥感、统计数据，分析发现 3 类主体功能区的生态和社会经济特征差异：（1）研究区域应用了 5 种草地恢复措施；（2）2000—2016 年间，重点开发区的草地恢复效果优于限制开发区和禁止开发区；（3）重点开发区的家庭纯收入最高；（4）重点开发区牧民对于草地保护和退化草地治理的认知和意愿比其他区域更为积极，该区牧民更多采用围栏+灭鼠+人工饲草地+暖棚舍饲措施。根据不同的发展目标，评估不同区域草地恢复措施的效果有助于促进草地可持续利用和理解区域生态承载力。

关键词：主体功能区；生态恢复措施；效果评价；黄河源区

Appendix

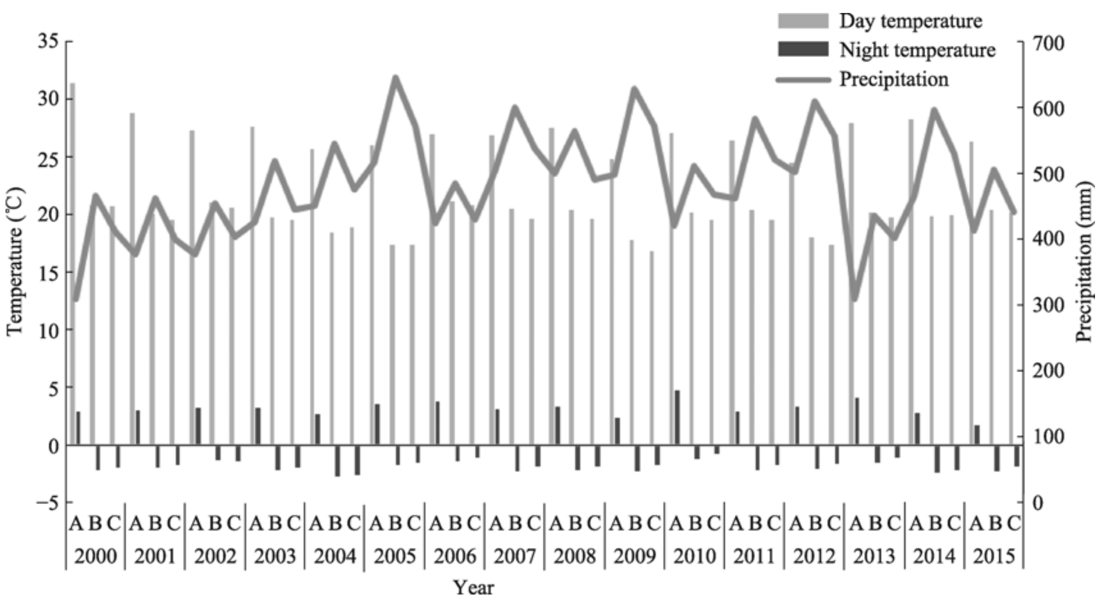

Fig. S　The trend of temperature and precipitation of the study area during 2000–2015
Note: A=Development prioritized zone; B=restricted zone; C= prohibited zone