Assessing the effects of ecological restoration approaches in the alpine rangelands of the Qinghai-Tibetan Plateau

Lin Zhen¹,², Bingzhen Du¹, Yunjie Wei¹,², Yu Xiao¹,² and Wenping Sheng³

¹ Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, People’s Republic of China
² School of Resource and Environment, University of Chinese Academy of Sciences, Beijing 100049, People’s Republic of China
³ Key Laboratory of Resources and Environmental Carrying Capacity Assessment of the Ministry of Land and Resources, Beijing 100812, People’s Republic of China

E-mail: zhenl@igsnrr.ac.cn

Keywords: ecological restoration approaches, NDVI, animal grazing, income, Qinghai-Tibetan Plateau

Abstract
Ecological restoration has increased in prominence since the last century as an active way to reverse ecosystem deterioration derived from human interventions. The goal of this study was to assess the impact of restoration approaches on ecological and economic conditions of typical regions in the Qinghai-Tibetan Plateau. Data were collected using structured questionnaires delivered to 195 herders living in areas with average elevation above 3773 m. Land use maps, MODIS images, and government statistics were also used for the study. It was found that local herders have adopted five major approaches, i.e. enclosure, grazing prohibition, enclosure + deratization, enclosure + deratization + grass seeding, and enclosure + deratization + crop-forage cultivation + warm sheds, to ensure success of the restoration programs initiated by the government. The results show that vegetation coverage, especially for high and very high coverage grasslands, increased across the study sites and across approaches used, with a high grassland recovery rate observed in the areas where either grazing is prohibited or grassland management was dominated by integration approaches.

Furthermore, households who employed integrated approaches tended to have more animals to rear, higher capability of resisting risks, and higher income than those who did not. These findings imply that balanced ecological and economic development is possible when appropriate management approaches are adopted. However, evaluation and monitoring of grassland conditions are needed to readjust restoration policy and associated approaches in a timely manner.

1. Introduction
Over the past several decades, socio-economic development in the larger countries of the Northern Eurasia region has been characterized by increasing levels of land use and regional environmental changes, which can have global consequences (Foley et al 2005, Lambin and Meyfroidt 2011, NEFI (Northern Eurasian Future Initiative) 2016, Groisman et al 2017, Monier et al 2017). Degradation of the land quality and ecosystems within this area has occurred at different scales (Reid et al 2000, MA (The Millennium Ecosystem Assessment) 2005, Liu et al 2016). At the global level, the goods and services that ecosystems provide have been significantly degraded (Sutton et al 2016). In 2011, the total value of global ecosystem services showed a decrease of USD 20.2 trillion yr⁻¹ from 1997, owing to land use and management changes (Costanza et al 1997, Costanza et al 2014) a trend that is currently continuing.

To slow the rate of environmental degradation, practitioners in many parts of the world have looked for active ways to reverse the damage; hence, ecological restoration has increased in prominence since the last century (Higgs 1997, Hobbs and Harris 2001). Many ecosystem restoration projects have been initiated in developed countries, including the USA and European countries (Nearing et al 1989, Thomas...
Principles for optimized land management (Jacobs et al. 2013), bio-suitability (Weeks et al. 2011), and eco-stability (Bullock et al. 2011) have been developed for integrated management of degraded zones (Williams 2015). The implementation of such projects has resulted in the creation of a series of restoration approaches and technologies, which have contributed significantly to the restoration of degraded ecosystems and are based on theories that explain the processes and mechanisms that damage ecosystems (Bullock et al. 2011, Kassam et al. 2014, UNEP (United Nations Environment Programme) 2014, UNDP (United Nations Development Programme) 2015).

As one of the large countries in the Northern Eurasia region, China's rapid economic development has been achieved at the cost of high levels of environmental degradation (Ouyang et al. 2016). The land area stricken by degradation processes accounts for approximately 22% of China's total land area (NDRC (National Development and Reform Commission of People's Republic of China) 2015), threatening the provision of ecosystem services as well as human welfare (Liu et al. 2006, Cao et al. 2009). To tackle such problems, the Chinese government began initiating ecological restoration projects, including the world's largest government-financed payment for ecosystem services programs: the Natural Forest Conservation Program and the Grain for Green Program (Ouyang et al. 2016). These initiatives have led to the development of approximately 214 core approaches and technologies, 64 modes, and more than 100 technological systems (Wang et al. 2009, Cheng 2012, Fu et al. 2013).

Recent research has shown that China's national conservation policies contributed significantly to the improvement of the overall ecosystem services from 2000 to 2010 (Ouyang et al. 2016). In particular, ecosystem services increased in the Sanjiangyuan region in the center of the Qinghai-Tibetan Plateau (QTP, the headwater region of the Yellow, Yangtze, and Mekong Rivers), which is a priority area for securing ecosystem services such as carbon sequestration, soil retention, sandstorm prevention, water retention, flood mitigation, and provision of habitat (Kammer et al. 2013). Grassland degradation was mitigated and production increased by 24.7%; net primary production increased by 45%; and runoff, provision of water resources to downstream regions, and water quality improved (Liu et al. 2016). Out of several approaches that were adopted, artificial vegetation restoration is increasingly gaining momentum in restoring sand dunes and improving the ecological environment in many desertification regions in the QTP and worldwide (Yong et al. 2005, Durán and Herrmann 2006, Castillo-Monroy et al. 2011, Li et al. 2017).

The scientific community advises special attention should be given to the assessment of how human populations will be affected by environmental changes and what management practices can be developed to help mitigate or allow adaptation to these changes (NEFI (Northern Eurasian Future Initiative) 2016, Monier et al. 2017). Subsequently, integrated and region-specific assessment models have been proposed (Boone et al. 2007, Bos et al. 2017, Monier et al. 2017). Existing studies in the region have largely focused on impact assessment of the conservation policies on the environment (e.g. Xu et al. 2013, Liu et al. 2016) and socio-economic conditions (e.g. Brown et al. 2013, Zhen et al. 2014, Koenig et al. 2015, Zhen and Du 2017), in order to better understand the coupled human–Earth system (e.g. Folke et al. 2002, Chen et al. 2015, Lee et al. 2015, Monier et al. 2017, Tong et al. 2017). However, they have not systematically examined the effects of the specific restoration approaches adopted in the environmental policies; thus, it is likely that science-based evidence that may support the process of proposing the effective approaches that can be introduced and adopted by the users has been lacking (Thiel 2009, Helming et al. 2013). In this study, we aimed to identify the major restoration approaches adopted by the representative households in the QTP, assess the impact of restoration programs and approaches on vegetation coverage, and analyze the characteristics of livestock grazing and income structure of the households adopting different approaches. It is expected that the findings will provide a basis for proposing the effective restoration approaches.

2. Methodology

2.1. Study area

QTP is known as Earth’s Third Pole and the Water Towers of Asia, thus environmental changes in this region affect ecological security of the surrounding areas (Ouyang et al. 2004, Piao 2010, Sun et al. 2012). The grassland area accounts for more than 60% of the total land area and is considered the most important place of the plateau because local livelihoods rely on it.

Four counties in the northeastern QTP were covered in the study: Maqin, Jiuzhi, and Maduo in Guoluo Autonomous Prefecture and Guinan in Hainan Autonomous Prefecture. The study area has an average elevation of 3773 m above sea level (asl). In 2015, 72.3% (3887 200 ha) of the study area was covered by alpine grasslands, followed by bare land (16.6%), forest land (6.0%), cropland (1.1%), water (3.9%), and built-up land (0.1%) (figure 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 climate conditions, with an annual average temperature ranging from −3.7 °C to 7.8 °C and annual precipitation between 421 mm and 773 mm in the four counties. About 90% of the total population in the three counties of Guoluo and 76% in the one county of Hainan belong to the Tibetan ethnic group (GAPBS (Guoluo Autonomous Prefecture Bureau of Statistics) 2016, HAPBS (Hainan Autonomous Prefecture Bureau of Statistics) 2016). Traditional animal grazing
has been practiced, with the main animals being yak and Tibetan sheep, which are suitable for grazing in alpine grassland (supplementary appendix table S1 is available online at stacks.iop.org/ERL/13/095005/mmedia).

2.2. Restoration programs and associated approaches adopted in the study area
A series of programs has been used to restore degraded grasslands in the study area since 2000. The most prominent strategy among them is the General Plan on Ecological Protection and Construction in Qinghai Sanjiangyuan Nature Reserve (2005–2013), which was approved by the State Council and took effect in 2005. Its second phase has been and will continue to be implemented from 2013 to 2020. 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. The main programs and associated approaches are summarized in supplementary appendix table S2.

2.3. Data and methods
2.3.1. Household surveys
Prior to the formal surveys, we conducted preliminary survey via individual interviews and group discussions with herders and key informants to guide the development of the formal questionnaire, and increase the validity of the results.

We used a stratified random sampling method (Weber and Tiwari 1992) to select the villages in our study. 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 four counties, which included alpine pastoral and agro-pastoral systems in highlands above 3500 m asl, average population density ranges from 2 to 10 persons km$^{-2}$, and distances between households on summer pasture of 5–20 km and were scattered throughout a large area of summer pasture. We used occasional random sampling (Weber and Tiwari 1992) for our survey, because no obvious pathways led through the villages. 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 two to three local people to translate the questions from Mandarin to Tibetan because over 73% of the respondents did not speak Mandarin. Completion of a questionnaire required 1–1.5 h.

Altogether, 195 households were interviewed, with 51, 43, 54 and 47 in Maqin, Jiuzhi, Maduo and Guinan counties respectively, 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 socio-economic characteristics of the household; 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.

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

We obtained NDVI images of the growing season (from the end of March to August) each year for the QTP from Zhang et al (2015), then generated annual NDVI data using the maximum value composite method after atmospheric correction and geometric correction using ENVI software. Generally, regional vegetation fraction coverage ($f_c$) is calculated based on the NDVI and the dimidiate pixel model (Li et al 2004), using the below formula (1):

$$
f_c = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}},
$$

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

3. Results

3.1. Restoration approaches adopted and associated features

As identified by the respondents, five ecological restoration approaches had been adopted in the study sites, i.e. enclosure, grazing prohibition, deratization, grass (perennial herbs) seeding, and crop-forage cultivations (annual herbs). Enclosure is a basic approach for grassland restoration that over 83.1% of households fenced their pasture (at least their winter pasture) with barbed wire. Deratization was another main approach and adopted by about 61% of households, mainly in the black soil of degraded grassland because of serious rodent damage. Grass seeding through perennial herb plantation has been applied in the Maduo and in other pastures where grazing is prohibited. Crop-forage plantation (annual herbs) and warm shed construction have been implemented mostly in Guinan (occupies 56% of the total). Herders normally used a combination of these five restoration approaches for different pastures: warm-season pastures (from June to October), cool-season pastures (from November to the following May), and unused grasslands (table 1).

The adoption of Approach C, which is a combination of the enclosure and deratization approaches, accounted for the largest number of households (45), whose grassland area was relatively lower (179.1 ha household$^{-1}$), followed by Approach A, or enclosure, which was adopted by 43 households. Next was Approach E, or a combination of enclosure + deratization + crop-forage (annual herbs) cultivation + warm shed approaches, which was used by 39 households and comprised smallest area of grassland, thus, additional crop-forage cultivation and warm shed construction can be adopted to increase the production efficiency. Then followed Approach D, or enclosure + deratization + grass seeding (perennial herbs), which was employed by 35 households. Last, Approach B, or grazing prohibition, was adopted by 33 households, who had the largest area of grasslands, that is, 925.0 ha household$^{-1}$ (table 1). This indicated that the incentive to adopt the restoration approaches was prompted by the availability of forage for livestock (Zhao et al 2000), as well as the specific problems causing grassland degradation.

The results show that there is no significant difference of household size ($p = 0.257$) and education level ($p = 0.079$) among those using different approaches. This can be explained that the research area is an aboriginality of nomadic, the family consisted mainly of two adults and two to three school-age children or elder. Meanwhile, the education level is very low (in average 4.2 years) compared to the provincial average (7.2 years) and national average (9.1 years) in the same year (NBSC (National Bureau of Statistics of the People’s Republic of China) 2017), implying that education level is not one of the diver forces to the adoption of different restoration strategies.

| Restoration approach | No. of HHs | HH size | Education level (years) | Warm-season pasture | Cold-season pasture | Unused grassland | Total grassland |
|----------------------|------------|---------|------------------------|---------------------|---------------------|-----------------|----------------|
| A                    | 43         | 5.0     | 3.8                    | 317.5 (61.8)        | 139 (27.0)          | 57.5 (11.2)     | 514.0          |
| B                    | 33         | 4.3     | 4.8                    | —                   | —                   | 925 (100.0)     | 925.0          |
| C                    | 45         | 5.5     | 3.7                    | 91.2 (50.9)         | 43.2 (24.1)         | 44.7 (25.0)     | 179.1          |
| D                    | 35         | 5.7     | 4.3                    | 128 (51.1)          | 54.8 (21.9)         | 67.5 (27.0)     | 250.3          |
| E                    | 39         | 6.1     | 4.6                    | 75.7 (55.1)         | 14.2 (10.3)         | 47.6 (34.6)     | 137.5          |

Average 39 5.3 4.2 122.5 (50.5) 50.2 (12.5) 228.5 (56.9) 401.2

Note. HH: household, unused grassland includes bare land and heavily degraded grassland, numbers in parenthesis are the percentages of the total. ‘-’ means value is unavailable because grazing is completely prohibited.

Table 1. Categories of ecological restoration approach adoption and associated features.
showed significant and only about 5.2% showed significant increasing trends, and supplementary appendix figure S1. Out of the five classes of vegetation coverage, IV (very high) and V (very high) coverage grassland increased from 58.4% to 60.6%, and I (very low) and II (low) coverage decreased from 24.0% to 21.6% during the same period. As a result, about 26.3% ($\Delta f_c$) of the grassland coverage showed significantly and slightly increasing trends, and only about 5.2% showed significantly and slightly decreasing trends (figure 2 supplementary appendix figure S2). Therefore, implementation of the ecological restoration programs has increased vegetation coverage and mitigated further degradation of the grasslands (also reported by Cai et al 2015). However, due to ecological fragility of the area, the grasslands with low and very low vegetation coverage is still vulnerable to both natural and human disturbance (Jiang and Zhang 2016, Sun et al 2016, Shao et al 2017).

Spatial variations of vegetation coverage change were observed among the counties studied (figure 2 and supplementary appendix figure S2). The most obvious $f_c$ increase was found in Guinan and Maduo, where Approach E was used by over 40% of households in Guinan (the highest percentage among the four study counties), thus, the combined effects of crop-forage (annual herbs) cultivation with warm sheds, enclosure, and deratization approaches allowed the grasslands to recover. As a result, very high coverage grassland increased from 41.4% to 49.0%, and low and very low coverage grassland decreased from 6.4%
and 14.4%, respectively, to 4.6% and 11.4% (figures 2(a), (b) and supplementary appendix figure S2). Overall, of the increased fec in Guinan, about 27.8% showed significant and slight increases (figure 2(c) and supplementary appendix figure S2).

In Maduo, where part of the Sanjiangyuan National Park is located, the main approaches applied were A (i.e. enclosure, by 22 households, or 40.7%) and B (i.e. grazing prohibition, by 22 households, or 40.7%), which provide time for the grasslands to recover. Thus, the percentage of very high plus high coverage grasslands increased from 37.0% to 38.9%. The total value of very low coverage and low coverage grasslands has decreased from 37.5% to 34.1% (figures 2(a), (b) and supplementary appendix figure S2). Overall, about 27.8% of vegetation coverage in Maduo showed significant and slight increase, only about 5.0% has shown significant and slight decrease (figure 2(c) and supplementary appendix figure S2).

The same trend was found in Maqin, where Approach D, or enclosure + deratization + grass seeding (22 households, or 43.1%), was dominant and Approach E (nine households, or 17.7%), Approach C (eight households, or 15.7%), Approach A (eight households, or 15.7%), and Approach B (four households, or 7.8%) were also used. About 1% increase of very high and high coverage grasslands (82.6% in the beginning stage and 83.6% in the current stage) and 0.5% decrease of very low coverage grasslands (3.0% in the beginning stage and 2.5% in the current stage) were found (figures 2(a), (b) and supplementary appendix figure S2). Overall, about 17.3% of vegetation coverage in Maqin showed significant and slight increases, whereas only about 5.1% showed significant and slight decreases (figure 2(c) and supplementary appendix figure S2).

In Jiuzhi, Approach C, or enclosure + deratization (21 households, or 48.8%) was dominant, followed by three other approaches (Approach E, nine households, or 20.9%; Approach A, eight households, or 18.6%; Approach B, five households, or 11.6%), and the very high coverage grassland has occupied more than 90% of the total grassland since 2000 (figures 2(a), (b) and supplementary appendix figure S2). Overall, about 9.6% of the vegetation coverage in Jiuzhi showed significant and slight increases, and about 9.2% showed significant and slight decreases (figure 2(c) and supplementary appendix figure S2).

3.3. Characteristics of livestock grazing of the households adopting different restoration approaches

Grazing of Tibetan sheep and yak is commonly practiced in the study area. The number of Tibetan sheep and yak respectively average about 70.6 (ranges from 0 to 680) and 52.3 (ranges from 0 to 295) heads per household (4.8 and 3.4 times higher than Guoluo’s average, respectively) (QPBS (Qinghai Provincial Bureau of Statistics) and NBSSOQ (NBS Survey Office in Qinghai) 2016). The overall number of horses was only about 1.2 heads per household, mainly for the purpose of transportation and recreational horse racing (supplementary appendix table S3). The households that have adopted Approaches D and E have a higher number of livestock, with the average number of animals at 241.8 and 200.6 heads, respectively. Of these animals, the Tibetan sheep are commonly grazed under Approaches D (164 heads) and E (132.7 heads) and about 45.4% and 52.6% of them are adult females and ewes, respectively. Approaches A and C are associated with households who had a small amount of livestock (about four to five times less than Approaches D and E), with average numbers of animals raised at 81.1 and 98.9 heads, respectively. Of these animals, yak is dominant, with 46.2 and 64.4 heads per household, respectively, followed by Tibetan sheep, with 32.8 (49% of which are adult females) and 32.2 (21% of which are adult females) heads per household, respectively. There was no livestock under Approach B, as it involves grazing prohibition.

The results show that the use of Approaches D and E obviously increased forage supply and the number of livestock breeding. The average area of grassland (ratio of available pasture area) was 250.3 ha (73%) and 137.5 ha (65.4%) for the herders adopting Approaches D and E, respectively, which was far less than that using Approach A (514 ha, or 88.8%), implying that the combined approaches are often recommended to and used by the households that have less but degraded grasslands than those that have relatively larger and better quality grasslands.

On the other hand, due to the high altitude and frequent occurrence of ice and snow disasters in the area, the forage shortage and extreme weather conditions are important causes of the high death rate of livestock (Wu et al 2015). Restoration approaches are considered useful strategies to protect the animals from natural disasters such as snowstorms. From our survey, the respondents reported that livestock loss from these natural disasters has decreased in recent years, especially for the herders who have adopted Approach E. Normally, the herders harvest grass forage in October and use it to feed their animals during the winter. Such practice significantly (p = 0.034) reduced the economic losses from natural disaster, in comparison with the practice of the enclosure only approach (A). In addition, the warm sheds have also increased the capacity to resist disaster, especially for young animals and adult females.

It was found that the average marketing rates of Tibetan sheep and yak were 18.2% and 8.3%, respectively, for the study sites, which are lower than the provincial averages (48.3% and 26.7%) and prefectural averages (54.4% and 20.1% for Guoluo; 51.4% and 38.6% for Hainan Prefectures) (QPBS (Qinghai Provincial Bureau of Statistics) and NBSSOQ (NBS Survey Office in Qinghai) 2016). This is because the number...
of animals grazed is relatively larger than the provincial and prefectural averages, the remoteness of the area constrains the access to market information and infrastructure, and the herders are strongly influenced by the Tibetan Buddhism religion, preferring not to kill the animals. However, the results indicated the difference of the marketing rate among the approaches, with relatively high rates for Tibetan sheep and yak found for Approaches E (22.4% and 10.6%, respectively) and D (20.3% and 9.3%), which are respectively 3%–9% (Tibetan sheep) and 2%–3% (yak) higher than those of Approaches A and C (supplementary appendix table S3).

3.4. Source of income of the households adopting different restoration approaches

The average household annual net income in the study sites was about 65 354 CNY (supplementary appendix table S4), which is higher than the national average rural household net income of 38 834.8 CNY (NBSC (National Bureau of Statistics of the People’s Republic of China) 2016) and the provincial average of 32 763.3 CNY household\(^{-1}\) year\(^{-1}\) (QPBS (Qinghai Provincial Bureau of Statistics) and NBSSOQ (NBS Survey Office in Qinghai) 2016). Income from agriculture and non-agriculture sources were nearly equal, with that from agriculture (animal sales, grazing-related subsidy) occupying 49.7% of the total and non-agriculture (Tibetan medicine, others) occupying rest 50.3%. Looking at the income structure, it is ranked as selling animals (19 018.8 CNY household\(^{-1}\) year\(^{-1}\) 29.1% of total) > Tibetan medicine (19 018.8, 27.6%) > others (14 867.9, 22.7%) > subsidy (13 448.5, 20.6%). Owing to high market demand and value, the collection of traditional Tibetan medicine, such as cordyceps and fritillary, is a popular income source of the local people.

Income structures and amounts varied among the households using different ecological restoration approaches (supplementary appendix table S4). In comparison with the households who adopted Approach A (enclosure was the only method for pasture management), income from Approaches B, C, D, and E was very significantly or significantly high (\(p = 0.045^{* *}, 0.673^{*}, 0.295^{*},\) and 0.047\(^{* * *}\)), respectively; these indicate the significant role of restoration approaches for increasing income. The ranking of total household annual net income (CNY) from high to low is Approach E (90 823.7) > Approach D (88 846.6) > Approach A (57 490.7) > Approach C (54 243.2) > Approach B (35 736.3) and is contributed to by different sources. Under Approach E, a significant (\(p = 0.002^{* * *}\)) income increase was observed from selling animals, with a total annual income of 37 182.6 CNY, or 40.9%, from animal grazing (the highest income among the different approaches), followed by Approach C, with income dominated by selling animals as well (36.8%).

Whereas under Approach D, income from Tibetan medicine accounted for about 47.5% of total income, given that about 62.9% of the households who applied Approach D are living in Maqin, where good quality cordyceps is produced (Zhang 2003). As for the households who mainly adopted Approach A or B, subsidy from the government is a main source of income, accounting for 34.5% and 56.4% respectively, owing to the fact that the pasture area is large under Approaches A and B and grazing is prohibited under Approach B.

In terms of household expenses for animal rearing, Approaches D and C have the highest expenses, accounting for about 23% of annual family total expenditure (supplementary appendix table S5), thus more money needs to be spent on purchasing grass forage under Approach D and pellet feed under Approaches D and C than under Approach E, because Approach E has a relatively smaller crop-forage cultivation area, as well as warm sheds, reducing the expenditure from forage purchase and animal loss.

4. Discussion

The study is significant for understanding the impact of restoration programs by linking to specific restoration approaches, and providing a basis for proposing the effective approaches. The findings of this study raise the following concerns: first, the results show that vegetation coverage has increased over the past 16 years, yet the forage supply is still insufficient because of prohibition of grazing and hay harvesting in large pastures. Herders and local officials need to have flexibility in policymaking and implementation, in order to have an improved system that balances ecological protection and sustainable livelihood. Some researchers also found that slight grazing is good for grass growth, increases carbon sinking (Shao et al 2017), and ensures herders’ income. This calls for the evaluation and monitoring of the grassland conditions and reclassification of the plots to either continuous prohibition of grazing or to open grazing.

Second, herders have clearly been experiencing economic losses from conservation activities; although they wanted to participate in conservation activities, they also expected sufficient compensation payments to mitigate their losses. As found from other studies, households feel they are not compensated sufficiently to participate in restoration programs, which may lead some herders to expand grazing into restricted grasslands or increase their number of animals, especially when the payments end (Bennett 2008, Zhen et al 2014), which potentially jeopardizes the success of the restoration programs.

Third, the suitable design of ecological restoration approaches could encourage the efficiency use of grasslands. The results show that the present grassland
conservation policy has decreased the trend of grasslands degradation. However, other key challenge is to sustain the livelihood of local residents, who earn most of their income from traditional animal husbandry. Therefore, instead of providing limited payment and requiring herdsmen to do both grazing and grassland protection, current practice in the Sanjiangyuan National Park can be expanded to cover the large area of the QTP, i.e. to provide job opportunities to the herdsmen who are affected by conservation programs, either through salaried work as a conservation agent managing the grasslands or via migration to other places with sufficient infrastructure for them to be able to settle down and look for off-farm income.

In addition, the study suggests that survey-based approach can provide important information to support model development that focus on the coupled human–earth system and assess the effectiveness of the ecological restoration strategies. The reasons include: (1) the survey-based approach can fill up the data gap for the model development by investigating relevant social-ecological facts and problems, local people’s willingness, attitude and perceptions, given that local people are ‘key players’ who are actually responsible for implementation of the decisions (Xu 2004, Xiao et al 2017). (2) The involvement of local people in the study is essential to understand the strengths and limitations on their interests (Reed et al 2009, Raum 2018), as well as social and economic impacts of the restoration programs on their livelihood. Comprehensive assessment of coupled human–earth system by using household survey is highlighted by the Chinese government for proposing the effective restoration approaches. (3) The survey-based findings can serve as a starting point for understanding the science–policy interface between local needs and scientific results, the direct or indirect causal relationship between the elements of the human and natural systems (Chen et al 2015), thereby enabling an integration of local needs into decision-making process.

In many previous researches, household characteristics (e.g. household size and education level) have been identified as the key internal factors, which attribute to adoption of different restoration strategies (e.g. Shi et al 2009, Zhang and Li 2014), and then consequence to the changes in livestock grazing and income (e.g. Alam 2013, Li et al 2015, Zhen and Du 2017). The external (natural) factors of ecosystem states (e.g. area, slope and elevation of grasslands), climate constraints (e.g. temperature and precipitation), changes of ecological condition (ecosystem degradation), and policy guidance can lead to differences in household’s production patterns (Du et al 2016, Xue and Zhen 2018). However, in this research, the changes of livestock grazing and income were oriented by implementation of ecological restoration approach. Because of (1) the external factors affect the adoption of different restoration strategies among five approaches (A, B, C, D and E); (2) the Chinese governments (political decisions) have a strong influence on choice of ecological restoration strategies, in most of the cases, herdsmen simply adopted recommended approaches; (3) natural factors have been distinguished and considered by governments as basic elements to develop the restoration approach during the decision making process.

5. Conclusions

Adoption of five restoration approaches has been playing significant roles for effective implementation of ecological restoration programs in the study area. Overall increase of vegetation cover was found. However, vegetation cover increase varied among the study sites and approaches used, and adoption of location-specific and problem-solving-oriented restoration approaches contributed significantly to the improvement of grassland coverage. It was found that the households who adopted more restoration approaches tended to have more animals to rear and sell, and have more income than those that did not. The results revealed that it is important to adopt integrated and location-specific restoration approaches by considering and assessing animal needs throughout the year and across the seasons.

It is concluded that combined use of restoration approaches, e.g. Approaches D and E in Guinan, can gain better results on increasing vegetation coverage than the others who did not, and the increase of vegetation coverage was the lowest in Jiuzhi where Approach C dominated. By assessing the characteristics of the herdsmen who used different approaches, it was found that there was no significant difference of the yak numbers among the herdsmen who adopted different restoration approaches, but the number of sheep was different, those who used Approaches D and E had more sheep than those with Approaches A and C. In addition, there were variations of income and expenditure among the herdsmen applying different approaches, with Approaches D and E greater than Approaches A and C for both income and expenditure.

The household survey-based approach used in this study can provide important information to support coupling with human–earth system and assess the effectiveness of the ecological restoration strategies, which facilitates the further review of restoration approach adjustment and amendment by the feedback from livelihood outcomes.

Acknowledgments

We thank the anonymous referees, and the editor for helpful comments. This research was funded by National Key Research and Development Program of China (No. 2016YFC0503700; 2016YFC0501906). We
extend our heartfelt thanks to Dr Pavel Grosman, NEFI-NEESPI Project Scientist, for his continuous encouragement and support to our research, and to Geoff Hart for his assistance polishing the language and for other valuable comments. We are grateful for the herders for their patient answering our questions and hospitality hosting us at homes in such high altitude places.

**ORCID IDs**

Lin Zhen @ https://orcid.org/0000-0001-6227-4697

**References**

Alam K 2013 Factors affecting public participation in river ecosystem restoration: using the contingent valuation method J. Dev. Areas 47 223–40

Bennett M T 2008 China’s sloping land conversion program: institutional innovation or business as usual? Ecol. Econ. 65 699–711

Boone R B, JACKETT J M, Galvin K A, Ojima D S and Tucker C J 2007 Links and broken chains: evidence of human-caused changes in land cover in remotely sensed images Environ. Sci. Policy 10 135–49

Bos A B et al 2017 Comparing methods for assessing the effectiveness of subnational REDD plus initiatives Environ. Res. Lett. 12 074007

Brown D G, Agrawal A, Sass D A, Wang J, Hua J and Xie Y C 2013 China’s sloping land conversion program on household income under enrollment and earning differentiation Environ. Monit. Assess. 82 40–52

Castilla-Monroy A P, Bowker M A, Maestre F T, Du B Z, Zhen L, Yan H M and de Groot R 2016 Effect of ecological restoration and management of sloping land on household incomes and livelihoods in northern China Environ. Res. Lett. 13 045001

Bullock J M, Aromon J, Newton A C, Pywell R F and Rey-Benayas J M 2011 Restoration of ecosystem services and biodiversity: conflicts and opportunities Trends Ecol. Evol. 26 541–9

Cai H Y, Yang X Y and Xu X L 2015 Human-induced grassland degradation/restoration in the central Tibetan Plateau: the effects of ecological protection and restoration projects Ecol. Eng. 83 112–9

Cao S Y, Li F, Wei Y J, Xie G D, Yang L and Zhen L 2009 Land use functions: conceptual framework and application for China Resour. Sci. 31 54–51 (in Chinese with English summary)

Castillo-Monroy A P, Bowker M A, Maestre F T, Rodriguez-Echeverria S, Martinez I, Barraza-Zepeda C E and Escolar C 2011 Relationships between biological soil crusts, bacterial diversity and abundance, and ecosystem functioning: insights from a semi-arid Mediterranean environment J. Veg. Sci. 22 165–74

Chen J Q et al 2015 Divergences of two coupled human and natural systems on the Mongolian Plateau BioScience 65 559–70

Cheng G D 2012 Integration of Ecological Restoration Experiment and Demonstration Research in Western China (Beijing: Science Press) (in Chinese)

Costanza R, d’Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O’Neill R V and Paruelo J 1997 The value of the world’s ecosystem services and natural capital Nature 387 253–60

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson S J, Kubiszewski I, Farber S and Turner R K 2014 Changes in the global value of ecosystem services Glob. Environ. Change-Human Policy Dyn. 24 152–8

Du B Z, Zhen L, Yan H M and de Groot R 2016 Effects of government grassland conservation policy on household livelihoods and dependence on local grasslands: evidence from Inner Mongolia, China Sustainability 8 1314

Durán O and Herrmann H J 2006 Vegetation against dune mobility Phys. Rev. Lett. 97 188001

Foley J A et al 2005 Global consequences of land use Science 309 570–4

Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling C S and Walker B 2002 Resilience and sustainable development: building adaptive capacity in a world of transformations Ambio 31 437–40

Fu B J, Liu G H and Ouyang Z Y 2013 Study of Ecological Regionalization of China (Beijing: Science Press) (in Chinese)

GAPBS (Guaoluo Autonomous Prefecture Bureau of Statistics) 2016 Statistical Communiqué on 2015 National Economic and Social Development of Guaoluo http://qhtjj.gov.cn/tjData/cityBulletin/201605/P020160525329509927026.doc (Accessed: 21 December 2017) (in Chinese)

Grosman P et al 2017 Northern Eurasia Future Initiative (NEFI): facing the challenges and pathways of global change in the twenty-first century Prog. Earth Planet. Sci. 4 41

HAPBS (Hainan Autonomous Prefecture Bureau of Statistics) 2016 Statistical Communiqué on 2015 National Economic and Social Development of Hainan http://qhtjj.gov.cn/tjData/cityBulletin/201605/P20160525_42289.html (Accessed: 21 December 2017) (in Chinese)

Helming K, Diehl K, Geneletti D and Wiggering H 2013 Mainstreaming ecosystem services in European policy impact assessment Environ. Impact Assess. Rev. 40 82–7

Higgs E 1997 Keepers of the secret chants: the poetics or ritual power in an Amazonian society by Jonathan D. Hil J. Am. Folklore 109 104

Hobs R J and Harris J A 2001 Restoration ecology: repairing the Earth’s ecosystems in the new millennium Restor. Ecol. 9 239–46

Jacobs D F, Dalgleish H J and Nelson C D 2013 A conceptual framework for restoration of threatened plants: the effective model of American chestnut (Castanea dentata) re-introduction New Phytol. 197 378–93

Jiang C and Zhang L B 2016 Effect of ecological restoration and climate change on ecosystems: a case study in the Three-Rivers Headwater Region, China Environ. Monit. Assess. 186 562

Kammer P M, Schob C, Eberhard G, Gallina R, Meyer R and Tschanz C 2013 The relationship between soil water storage capacity and plant species diversity in high alpine vegetation Plant Ecol. Divers. 3 457–66

Kassam A, Derpsch R and Friedrich T 2014 Global achievements in global value of ecosystem services and natural capital BioScience 64 70–8

Kubiszewski I, Farber S and Turner R K 2014 Changes in the global value of ecosystem services Sci. Adv. 10 074007

Kammer P M, Schob C, Eberhard G, Gallina R, Meyer R and Tschanz C 2013 The relationship between soil water storage capacity and plant species diversity in high alpine vegetation Plant Ecol. Divers. 3 457–66

Lee J H, Kakinuma D, Okuro T and Iwasa Y 2015 Coupled social and environmental change in the Three-Rivers Headwater Region, China Environ. Monit. Assess. 188 562

Koenig H J et al 2015 Knowledge brokerage for impact assessment of land use scenarios in Inner Mongolia, China: extending and testing the FoPIA approach Sustainability 7 5027–49

Lambin E F and Meyfroidt P 2011 Global land use change, economic globalization, and the looming land scarcity Proc. Natl. Acad. Sci. USA 108 3465–72

Lee J H, Kakinuma D, Okuro T and Iwasa Y 2015 Coupled social and ecological dynamics of herders in Mongolian rangelands Ecol. Econ. 114 208–17

Li H, Yao S, Yin R and Liu G 2015 Assessing the decadal impact of China’s sloping land conversion program on household income under enrollment and earning differentiation Forest Policy Econ. 61 95–103

Li M M, Wu B F, Yan C and Zhou W F 2004 Estimation of vegetation fraction in the upper basin of Miyun Reservoir by remote sensing Resour. Sci. 26 153–9 (in Chinese with English summary)

Li Y F, Li Z W, Wang Z Y, Wang W L, Jia Y H and Tian S M 2017 Impacts of artificially planted vegetation on the ecological restoration of movable sand dunes in the Mugetan Desert, northeastern Qinghai-Tibet Plateau Int. J. Sediment Res. 32 277–87

Liu J Y, Yue T X, Ju H B, Wang Q and Li X B 2006 Integrated Ecosystem Assessment of Western China (Beijing: China Meteorological Press) (in Chinese)

Liu J Y, Yue T X, Ju H B, Wang Q and Li X B 2006 Integrated Ecosystem Assessment of Western China (Beijing: China Meteorological Press) (in Chinese)

Muyun Reservoir by remote sensing Resour. Sci. 26 153–9 (in Chinese with English summary)

Li Y F, Li Z W, Wang Z Y, Wang W L, Jia Y H and Tian S M 2017 Impacts of artificially planted vegetation on the ecological restoration of movable sand dunes in the Mugetan Desert, northeastern Qinghai-Tibet Plateau Int. J. Sediment Res. 32 277–87

Liu J Y, Yue T X, Ju H B, Wang Q and Li X B 2006 Integrated Ecosystem Assessment of Western China (Beijing: China Meteorological Press) (in Chinese)

Liu J Y, Yue T X, Ju H B, Wang Q and Li X B 2006 Integrated Ecosystem Assessment of Western China (Beijing: China Meteorological Press) (in Chinese)
MA (The Millennium Ecosystem Assessment) 2005 Ecosystem and Human Well-being: Policy Response, Findings of the Responses Working Group (Washington D C: Island Press)

Monier E, Kicklighter D W, Sokolov A P, Zhuang Q L, Sokolik I N, Lawford R, Kappas M, Paltsev S V and Groisman P Y 2017 A review of and perspectives on global change modeling for Northern Eurasia Environ. Res. Lett. 12 038001

NBSC (National Bureau of Statistics of the People’s Republic of China) 2016 China Statistical Yearbook, of 2016 (Beijing: China Statistics Press)

NBSC (National Bureau of Statistics of the People’s Republic of China) 2017 China Statistical Yearbook, of 2017 (Beijing: China Statistics Press)

NDRC (National Development and Reform Commission of People’s Republic of China) 2015 Major Function Oriented Zoning of China (Beijing: People’s Publishing House) (in Chinese)

Nearing M A, Foster G R, Lane L J and Finkner S C 1989 A process-based soil erosion model for USDA-water erosion prediction project technology Trans. ASAE 32 1587–93

NEFI (Northern Eurasian Future Initiative) 2016 The NEFI science plan executive summary: Northern Eurasia Future Initiative (NEFI) facing the challenges and pathways of global change in the 21st century http://neespi.org

Ouyang H 2009 The eco-system interface processes and their links to climatic changes on the Plateau Uplifting of Tibetan Plateau with Its Environmental Effects ed D Zheng et al (Beijing: Science Press) pp 401–8

Ouyang Z, Zheng H, Xiao Y, Polakry S, Liu J, Xu W, Wang Q, Zhang L, Xiao Y and Rao E M 2016 Improvements in ecosystem services from investments in natural capital Science 352 1455–9

Piao S L et al 2010 The impacts of climatic change on water resources and agriculture in China Nature 467 743–51

QPBS and NBSSOQ (Qinghai Provincial Bureau of Statistics; NBS Survey Office in Qinghai) 2016 The Statistical Yearbook of Qinghai Province (Xining: QPBS and NBSSOQ) (http://qhtjj.gov.cn/nj/2016/index.htm) (Accessed: 21 December 2017) (in Chinese)

Raum S 2018 A framework for integrating systematic stakeholder analysis in ecosystem services research: stakeholder mapping for forest ecosystem services in the UK Ecosyst. Serv. 29 170–84

Reed M S, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn C H and Stringer L C 2009 Who’s in and why? A typology of stakeholder analysis methods for natural resource management J. Environ. Manage. 90 1933–49

Reid R S, Kruza R L, Muthui N, Taye A, Wotton S, Wilson C J and Mulatu W 2000 Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia Landsca. Ecol. 15 339–55

Shao C L et al 2017 Grassland productivity and carbon sequestration in Mongolian grasslands: the underlying mechanisms and nomadic implications Environ. Res. 159 124–34

Shi M J, Tao W C and Zhao X T 2009 Farmers’ land use decision and policy choices for ecological restoration under constraints of water resources in oasis region of China Arid Land Geogr. 32 274–80

Sun H L, Zheng D, Yao T D and Zhang Y L 2012 Protection and construction of the national ecological security shelter zone on Tibetan Plateau Acta Geogr. Sin. 67 3–12 (in Chinese with English summary)

Sun Q L, Li B L, Xu L L, Zhang T, Ge J S and Li F 2016 Analysis of NVDI change trend and its impact factors in the Three–River Headwater Region from 2000 to 2013 J. Geo-inf. Sci. 18 1707–16 (in Chinese with English summary)

Sutton P C, Anderson S J, Costanza R and Kubiszewski I 2016 The ecological economics of land degradation: impacts on ecosystem service values Ecol. Econ. 129 182–92

Thomas H, Dieter G and Li H 2012 Environmental Governance in China and Germany from a Comparative Perspective (Beijing: Central Compilation & Translation Press) (in Chinese)

Thiid A 2009 The use of ex-ante modelling tools in European Impact Assessment: what role does land use play? Land Use Policy 26 1138–48

Tong Y X, Liu J G, Li X L, Sun J, Herzberger A, Wei D, Zhang W F, Dou Z X and Zhang F S 2017 Cropping system conversion led to organic carbon change in China’s mollisols regions Sci. Rep. 7 15806

UNDP (United Nations Development Programme) 2015 UNDP in Focus 2014/2015—Time for Global Action (New York: UNDP)

UNEP (United Nations Environment Programme) 2014 UNEP Yearbook 2014: Emerging Issues in Our Global Environment (Nairobi: UNEP)

Wang J, Jiang Z D, Lian P, Guo M C, Jiang J, Su X, Li H and Niuy L 2009 Coupling analysis of the agricultural ecological economic system over 70 years in the Zhihanggou Watershed, Shanxi Province Acta Ecol. Sin. 29 5136–7 (in Chinese with English summary)

Weber K E and Tiwari I P 1992 Research and Survey Format Design: An Introduction (Bangkok: Asian Institute of Technology) p109

Weeks A R et al 2011 Assessing the benefits and risks of translocations in changing environments: a genetic perspective Evol. Appl. 4 709–25

Williams J 2015 Soils governance in Australia: challenges of cooperative federalism Int. J. Rural Law Policy 1 1–12

Wu X H, Hou G L, Wang J M and Wang Q B 2013 Spatio-temporal analysis on snow disaster of Qinghai Province from 1950 to 2000 J. Qinghai Environ. 2 59–64 (in Chinese)

Xiao L S, Zhang Q G, Zhu Y and Lin T 2017 Promoting public participation in household waste management: a survey based method and case study in Xiamen city, China J. Clean. Prod. 144 313–22

Xu W 2004 The changing dynamics of land-use change in rural China: a case study of Yuhang, Zhejiang Province Environ. Plan. A 36 1595–615

Xu Z R, Cheng S K, Zhen L, Pan Y, Zhang X Z, Wu J X, Zou X P and Dhruva Bijaya G C 2013 Impacts of dung combustion on the carbon cycle of alpine grassland of the North Tibetan Plateau Environ. Manage. 52 441–9

Xue Z C and Zhen L 2018 Impact of rural land transfer on land use functions in western China’s Guyuan based on a multi-level stakeholder assessment framework Sustainability 10 1376

Yong Z S, Tong H Z and Yu L L 2005 Changes in soil properties after establishment of Artemisia halodendron and Caragaminicophylla on shifting sand dunes in semi-arid Horqin sandy land, Northern China Environ. Manage. 36 272–81

Zhang J C 2003 The situation and resource management of cordyceps in Guoluo Qinghai Prataculture 12 53–7 (in Chinese with English summary)

Zhang X Z et al 2015 Ecological change on the Tibetan Plateau Chin. Sci. Bull. 60 3048–56 (in Chinese with English summary)

Zhang Y and Li S 2014 The impact of environmental preferences on public supporting for the river ecosystem restoration program in China Soc. Sci. Electron. Publish. 9 55–64

Zhang Y L, Li B Y and Zheng D 2014 GIS dataset of the boundary and area of the Tibetan Plateau in China (DBATP) Glob. Change Res. Data Publ. Reposit. 1 (in Chinese)2014.01.12.V1

Zhao X Q, Zhang Y S and Zhou X M 2000 Theory and practice for forest ecosystem services in the Xilingol League of Inner Monglia, China J. Environ. Manage. 61 28–34

Zhou J J, Jiang Z D, Lian P, Guo M C, Jiang J, Su X, Li H and Niu Y L 2015 Plan. 1595–615