Land Use Policy 113 (2022) 105896

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Improving herders' income through alpine grassland husbandry on Qinghai-Tibetan Plateau

Qian Qian [a,b], Junbang Wang [a,c,*], Xiujuan Zhang [b,**], Shaoqiang Wang [a], Yingnian Li [c], Qinxue Wang [d], Alan E. Watson [e], Xinquan Zhao [c]

[a] National Ecosystem Science Data Center, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[b] College of Horticulture and Gardening, Yangtze University, Jingzhou 434023, China

[c] Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining 810008, China

[d] Center for Regional Environmental Research, National Institute for Environmental Studies, Tsukuba 12305-8506, Japan

[e] USDA Forest Service, Rocky Mountain Research Station, Missoula, MT 59801, USA

ARTICLE INFO

Keywords:
Ecological conservation
Herders' income
Sustainability
Grassland use

ABSTRACT

Promoting sustainability of ecosystems and economic development is a dual national objective in China, as well as one of the sustainable development goals (SDGs) of the United Nations. The Three-River Headwaters Region, where a National Park initiative has been initiated in the pastoral region of the Qinghai-Tibetan Plateau, is one of the key pilot projects in China with sustainability targets for 2025 and 2035. This paper assesses the possibility of achieving established targets for the proportion of cultivated to available grassland. These targets consider both ecosystem protection and herders' livelihoods. An income simulation model was first developed to estimate the percentage of cultivated grassland area necessary from the natural grasslands to achieve the target income. The model was developed using income and livestock data from the annual yearbook for 2018, then applied to estimate conditions for three counties in the eastern region. Presently the rangelands are seriously overgrazed with income just reaching above the poverty level. If livestock were decreased to a theoretical carrying capacity level, income would decrease to lower than the poverty level, even considering a livestock feeding system to achieve higher production levels. Under these circumstances, in order to reach income targets in 2025, one option centered on income production from livestock requires 5% of grasslands to be cultivated to produce forage for livestock. However, achieving income targets in 2035 will become very difficult because the needed proportion was estimated to increase to 14%. An alternative was to transport extra forage from the agriculture region of eastern Qinghai province. The local government should consider these two options to improve herders' income along with maintaining the traditional nomadic culture and sustainable ecosystems. The approach used to develop and apply this model could be applied to predict income changes accompanying future climate scenarios and to propose policies aimed at sustainability of ecosystems and economies for grasslands worldwide.

1. Introduction

A win-win goal of enhancing livelihoods and conserving pastoral lands has great challenges and involves very complex and multiple dimensions in law and policy, land use rights, ecosystem management, and cultural conventions (Hua and Squires, 2015; Gongbuzeren et al., 2018; Kemp, 2020). From the view of ecosystem management, sustainability can mean protection and restoration programs for degraded grasslands, eco-compensation, and cultivated grass-based livestock husbandry (Zhao et al., 2018). The policy of eco-compensation has contributed great positive effects to improve livelihoods in the short-term (Liu et al., 2019; Yin et al., 2019; NFGA, 2020), but benefits have been highly debated and may not be considered sustainable due to dependence on external policies and input (Huang et al., 2018; Zhao et al., 2018; Yin et al., 2019).

Sustainable livestock husbandry is often dependent upon development of cultivated grassland, a topic which has been substantially

* Corresponding author at: National Ecosystem Science Data Center, Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.

** Corresponding author.

E-mail addresses: jbwang@igsnrr.ac.cn (J. Wang), 496540745@qq.com (X. Zhang).

https://doi.org/10.1016/j.landusepol.2021.105896
Received 15 November 2020; Received in revised form 31 August 2021; Accepted 21 November 2021
Available online 29 November 2021

Nomenclature

Cultivated grassland Where oats, peas and other crops are planted for achieving higher forage yield.
N% Is the proportion of cultivated grassland area to available grassland area.
GLOPEM-CEVSA Is a remote sensing coupling ecosystem process model and applied to estimate net primary production (NPP).
GLCV-Income Is an income model based on GLOPEM-CEVSA, which estimates N% from the NPP simulated by the GLOPEM-CEVSA under the given economic target for pastoralists' income.
SISGC Is Subsidy and Incentive System for Grassland Conservation. As a policy, it encourages herdsmen to protect the ecological environment and reduce animal husbandry production by giving good seed subsidies, forbidding grazing subsidies, and balancing incentives for grass and livestock.
GLiH Grass-based Livestock Husbandry, is a kind of husbandry that developed ecologically-sound approaches to producing grass-fed livestock with utilization of only a small land area for cultivation of forage crops to protect the vast but fragile grassland (Fang et al., 2018).

researched (Ren, 2013; Fang et al., 2018; Zhao et al., 2018; Kemp, 2020). Ren et al. (2016), for instance, advocated the concept of grassland-agriculture to fully utilize non-food outputs from agriculture to support animal husbandry. Fang et al. (2018) advocated the concept of "Grass-based Livestock Husbandry" based on research on temperate steppe locations, which is a relatively resource-rich grassland, to develop ecologically-sound approaches to producing grass-fed livestock with utilization of only a small land area for cultivation of forage crops to protect the vast but fragile grassland. However, on Qinghai-Tibetan Plateau, with its more fragile grasslands, ecological security and pastoralists' livelihoods might be evaluated through a regional coupling model, proposed for optimal utilization of grass-livestock resources to determine proportion targets, termed the "N% concept", i.e., the minimum conservation area to protect biodiversity and ecosystem services and the optimal area for local pastoralists' livelihoods, on the regional scale (Zhao et al., 2018; Li et al., 2019). Some studies found that by stocking rate reductions of as much as 50%, large swaths of grasslands could be rehabilitated and herder incomes from livestock could be improved (Behrendt et al., 2020; D. Kemp, 2020; D.R. Kemp et al., 2020).

Livestock carrying capacity, the maximum number of animals that an area of land can support on a sustainable basis, has been used widely as a tool in grassland management (Xu, 2014; Zhang et al., 2014; Meshesha et al., 2019; Lee, 2020). Though carrying capacity is highly variable across years due to high interannual variability of rainfall and grazing management (Golluscio et al., 2015; Cheng et al., 2017; Meshesha et al., 2019), long-term average carrying capacity may be roughly estimated to match stocking rates with forage supply and maximizes long-term profitability (O'Reagain et al., 2014; Cheng et al., 2017). Within this conceptual framework, though the carrying capacity-based method has been questioned (Hruska et al., 2017b; Gongbuzeren et al., 2018; Guo et al., 2020; Kemp, 2020), stocking rates have been estimated from long-term average measurements and widely applied (Zhang et al., 2015; Bryan et al., 2018; Du et al., 2019). Past applications suggest that impacts on income in the future may be estimated by incorporating other uncertainties as well, such as those related to climate change effects, or new agrohusbandry techniques.

The Three-River Headwaters (TRH), located in the hinterland of the Qinghai-Tibetan plateau, also known as the 'Water Tower of Asia', is the source of the Yellow River, Yangtze River, and Lantsang River (Chen et al., 2020; Kemp, 2020). Its grasslands provide crucial ecosystem services for humans from local to global (Dong, 2020; Ouyang et al., 2020b). However, it has been estimated that from about 35–50% of its area has been seriously degraded (Li et al., 2014b), and though the trend has been reduced somewhat, it is still far from an optimal condition (Shao et al., 2017). Meanwhile, the livelihoods of nearly 6 million Tibetan people are almost completely dependent on natural grassland-based husbandry. Therefore, this region needs great changes to improve livelihoods and protect and restore its threatened natural grasslands, for potential applications in other grassland ecosystems worldwide (Bilgen and Sarıkaya, 2015; Sun et al., 2020).

Three-River-Source National Park was included as part of a national pilot project in 2016, aimed at achievement of a system of IUCN Category 2 Protected Areas in China (Tian and Fang, 2017; Ouyang et al., 2020a). However, there is available grassland for use of about 74,300 km^2 in a total area of 123,100 km^2, or about 31.71% of the TRH in 22 counties (Fig. 1), and an area of 54.37% is in the moderate or severe degraded condition. Meanwhile, in the park, there is a population of 64, 000 with the per capita net income of RMB 5876 (NDRC, 2018). Therefore, overall targets were planned to restore degraded ecosystem services and improve biodiversity, with net income per capita expected to arrive at RMB 14,000 in 2025 and 25,000 in 2035, respectively (NDRC, 2018). The income projections have included government ecological subsidies and wages as conservation protectors or part-time workers for the Park. However, questions remain about whether the livelihoods will be sustainable if policy-based subsidies cannot be continued. Realizing overall income goals is of concern to not only the local government but also to international society facing the same problems of sustainable grasslands development, for the income (and thus, quality of life) of herders is considered a fundamental factor in protection of grasslands (Zhao et al., 2014; Hruska et al., 2017a; Zang et al., 2020).

The "N% concept," commonly used to project conservation and income sustainability targets, was revised to be the proportion of cultivated grassland to total grassland in this study. Therefore, the "N% concept" was applied to address the following questions: (1) what is the proportion of production land necessary to maintain the present livelihood and (2) how much would the proportion need to change to achieve future income targets, such as those projected for 2025 and 2035?

2. Study area

Considering the relatively favorable climatic conditions, higher yielding grasslands, and relatively developed livestock industry, three counties in the eastern Three-River Headwaters region, Qinghai Province, China, were selected as the study area (Fig. 1). Located about 100 km from the nearest national park in the region, the study area embraces approximately 4048 km^2 of nature reserves, representing 22.6% of the study area. As Table 1 shows, the area has an alpine climate with the annual mean temperature of 0.4–14.6 ℃ and annual total precipitation of 440–615 mm. The vegetation mainly is alpine meadow with the dominant species of *Kobresia pygmaea*, *Kobresia humilis* and *Stipa purpurea* Griseb (Sun et al., 2011). Tongde, with an average altitude of 3660 m, is considered one of the primary areas of barley production. Since 2013, its forage seed varieties have improved more than 80%, based on higher yield, and its livestock breeds have improved over 65% on their meat and milk production. Henan, with most areas above 3600 m (the highest altitude is 4539 m), is a pure pastoral county. Zeku, mostly above 3500 m, is a developing and lower-income county, where animal husbandry is the main industry. The three counties have achieved previously set poverty alleviation goals in recent years (Table 1).

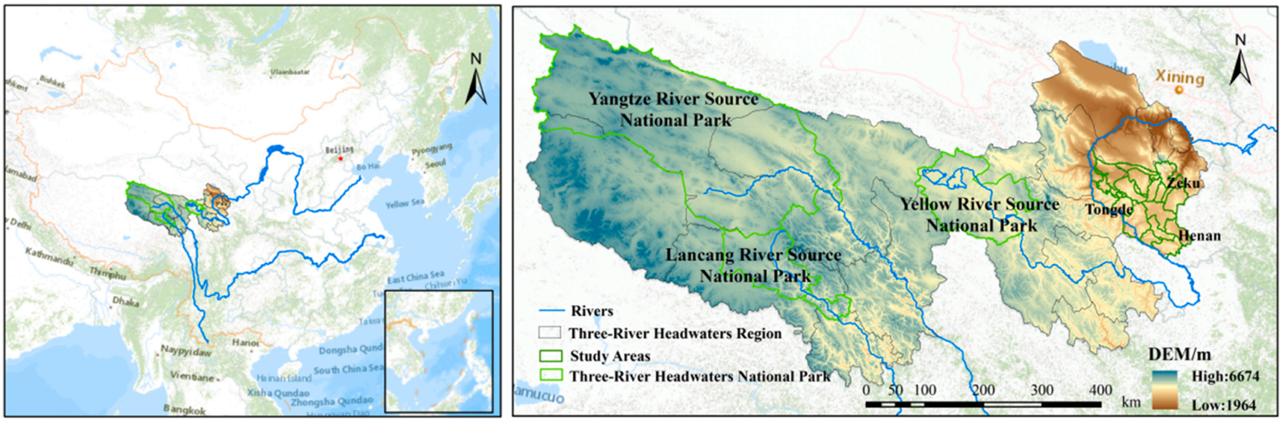

Fig. 1. Three counties with livestock in the eastern Three-River Headwaters region (TRH), Qinghai Province, China, were as selected as the study area. The area has a distance of about 100 km from the nearest part of the National park and overlays with some natural conserved areas.

Table 1
The natural conditions and socio-economic statistics of the study area of Tongde, Henan, and Zeku Counties, in the eastern Three-River Headwaters region, Qinghai Province, China. The data for the National Park located 100 km west of the study area are also given as a reference.

Status		Tongde	Zeku	Henan	National Park#
Average Elevation (m)		3655	3763	3736	4715
≥ 0 ℃ Accumulated Temperature (°C)		1432	1163	1265	655
Annual total Precipitation (mm)		504	567	610	384
Population		54,595	73,534	34,327	64,600
GDP in 2018 (M. CNY)	Primary Industry	825	823	747	1687
	Secondary Industry	215	351	452	459
	Service Sector	337	453	438	565
	Total	1377	1627	1637	2711
Net Income (CNY/Rural person)	Current Net Income	10,976	7325	10,725	8050
	Operating Income	6611	4457	–	–
	Target* in 2025	14,000	14,000	14,000	14,000
	Target* in 2035	25,000	25,000	25,000	25,000

The GDP and net income data of the national parks are based on the statistical yearbook data of the administrative counties in which they are located, and there are large deviations due to the imperfect spatial coverage of the two, thus these data are only used as a reference and not the actual data of the national parks.

* The net income target in 2025 and 2035 were based on the master plan for Three-River-Source National Park (NDRC, 2018).

3. Data and methods

3.1. Data sources

The actual forage yield was estimated through a net primary production (NPP) dataset (Wang, 2021) produced from a remote sensing-based model. The intent of the model used is to decrease uncertainties by considering the spatial heterogeneity in the same vegetation classification and simulating the ecosystem process, such as photosynthesis, autotrophic respiration, and evapotranspiration, etc. and quantifying impacts from climate changes (Wang et al., 2009, 2011a; Yang et al., 2019). Specifically, the NPP estimates were derived from a "light use efficient model" and used to estimate the grassland yield and theoretical livestock numbers and income in 2018 for the study area of the Three-River Headwaters Region. The model's main inputs include remotely sensed Fraction of Photosynthetically Active Radiation (FPAR) and interpolated climate data. The FPAR was estimated from the surface reflectance products (MOD09Q1) of the Moderate Resolution Imaging Spectroradiometer (MODIS) at a spatial resolution of 250 m and a time step of eight days (Liu et al., 2007). To match the resolution of the remote sensing data, the climatic data were interpolated to the same spatial and temporal resolution from the observations on the meteorological stations, and included air temperature, precipitation, wind speed, sunlit hours and air relative humidity. Forage yield-based livestock rates were used to estimate herders' income by considering spatial heterogeneity through the FPAR data. The model has been applied in this region in previous studies (Fan et al., 2010; Shao and Fan, 2018; Zhang et al., 2018a, 2018b).

The land use and land cover (LUCC) data in 2015 were derived using Landsat 8 remote sensing imagery at a resolution of 30 m (http://www.resdc.cn) (Xu et al., 2018). The LUCC data were classified using a three-level classification system, and grassland data were extracted and further analyzed in this study (Liu et al., 2003, 2005, 2010a).

The year-end stock, per capita income, and other socio-economic data were drawn from the Agricultural and Livestock Statistics Yearbook for 2017, Henan County Statistical Yearbook for 2018, Zeku County Statistical Yearbook for 2018, and Tongde County Statistical Yearbook for 2018.

The population within the pastoral area was predicted by using a Logistic model (Wang et al., 2014). The results are mainly predicted from the existing population size, resources and environment, and will tend to be flat in later stages of projections. The rise of ecological migration in China began in the early 1980 s, mainly moving the population located in ecologically fragile areas or important ecological functional areas and areas with poor natural environment conditions to other areas. However, such movement efforts were not included in projections and the future pastoral population is not expected to be greatly reduced in the three counties of the study area.

3.2. Methods

The concept of N% was revised as the percent of land area used for cultivation to total grasslands and analyzed to project income goals in 2025 and 2035 at the township scale through a livestock-based income model, GLCV-Income. The GLCV-Income model was adapted from a previously developed model, GLOPEM-CEVSA, which estimates net primary productivity (NPP) with the inputs of remotely sensed FPAR and interpolated climate data (Wang et al., 2009, 2011a). The new GLCV-Income model extended its sub-modules to calculate grass yield, the theoretical and actual carrying capacity, and the theoretical per capita income (Fig. 2), which are described in detail in the following paragraphs. The model needed aboveground biomass measures from the field, and livestock-related and actual per capita income data for model validation.

3.2.1. Grazing pressure index

The grazing pressure index (*Ip*), defined as the ratio of the actual to the theoretical livestock carrying capacities (Fan et al., 2011), was used to evaluate the status of grazing productivity and utilization of the grasslands and was calculated by the following:

$$Ip = Cs/Cl \tag{1}$$

$$Cs = \frac{Cn \times (1 + Ch)}{Ar} \tag{2}$$

The *Cs* is the actual livestock carrying capacity; *Cn* is the year-end livestock numbers, *Ch* is the livestock slaughter rate; *Ar* is the available grassland area. The slaughter rates were calculated from the sold numbers of livestock in a year and the number of stock at the beginning of the year. Taking Zeku as an example, in 2018, the sold sheep and yaks were 316,600 and 60,600 respectively, and their numbers at the beginning of the year were 358,000 sheep and 181,700 yak. Therefore, the slaughter rates were 88% (sheep) and 33% (yak). Similarly, the slaughter rates in Tongde were 46% (sheep), 28% (yak), whereas those in Henan were 64% (sheep), 51% (yak) in 2018. The standard sheep unit was used from national standards, defined as one mature sheep with a net weight of 50 kg and a lamb up to half a year old. One yak is equivalent to four sheep units (Zhou, 2001; MOA, 2015). The ratio of sheep to yak were calculated according to the statistic year-book data converted to sheep units as the 1:2 for Zeku, which were used to estimate the number of sheep and yaks from the theoretical livestock carrying capacity.

The *Cl* was calculated for each township according to Fan et al. (2010):

$$Cl = \frac{Ym \times Ut \times Co \times Ha}{Sf \times Gt} \tag{3}$$

where *Cl* is the theoretical livestock carrying capacity expressed in sheep units (SU/hm^2) (Rees, 1996), *Ym* is the grassland yield (kg/hm^2), *Ut* is the utilization rate of herbage, *Co* is the proportion of the area available for pasture, *Ha* is the rate of edible grazing grass, *Sf* is the daily required amount of edible hay per SU, and *Gt* is the grazing time. Here, the *Ut*, *Co* and *Ha* were given the values of 70%, 92% and 80% according to Fan et al. (2011). Meanwhile the Sf is 1.8 kg based on the Agricultural industry standards NY/T 635–2015. Because the grasslands are used during both warm and cold seasons, the total grassland was assumed to be grazed the whole year, that is, $Gt = 365$.

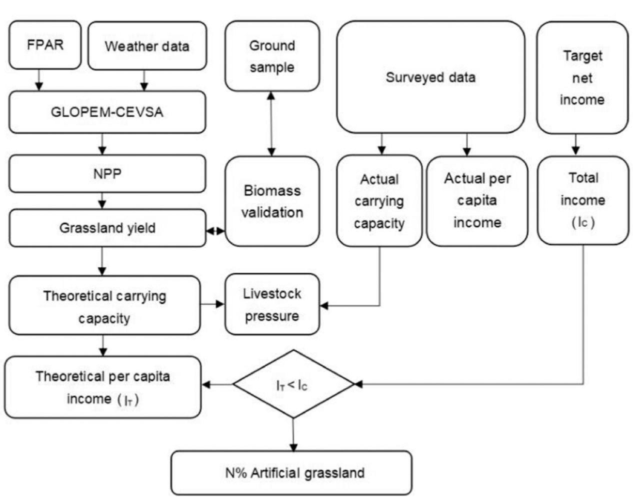

Fig. 2. Flowchart of the simulation analysis of scenarios of pastoralist income based on N% theory.

The grassland yield (*Ym*) was calculated from the net primary productivity (*NPP*) and the ratio of belowground to aboveground NPP was estimated from aboveground and belowground biomass sample data (Fan et al., 2011). In order to reduce the impact of climate fluctuations on grassland yield in future scenarios, the mean NPP from 2000 to 2018 was used to calculate long-term carrying capacity for each township.

$$Ym = NPP/(1 + BNPP/ANPP) \tag{4}$$

$$BNPP = BGB \times (liveBGB/BGB) \times Turnover \tag{5}$$

$$Turnover = 0.0009(g/m^2) \times ANPP + 0.25 \tag{6}$$

where *NPP* (gC/m^{2}a, convert to dry matter weight by the carbon content of 50%) is calculated using the fraction of photosynthetically active radiation absorbed by vegetation (FPAR) and light use efficiency (Wang et al., 2011a). The *BNPP* is the belowground *NPP* of the vegetation, the *ANPP* is its above-ground NPP assuming it is equal to aboveground biomass (*AGB*) for grassland, and *BGB* is the belowground biomass. The *live BGB/BGB* was set to 0.79 (Liu et al., 2010b), and *Turnover* (1/a) is the turnover time of the roots.

3.2.2. Income using crop straw and chaff

The crop straw and chaff from agricultural fields can be used in husbandry as extra feed to increase annual income per capita. The ratio of crop straw to grain was used to estimate straw production from the crop grain yield according to data in the yearbooks consulted, using the equation below:

$$WS = WP \times SG \tag{7}$$

$$IF = \frac{\mathrm{WS} \times Ch \times Sp}{Sf \times Gt \times P} \tag{8}$$

where *WS* is straw production (kg/hm^2); *WP* is the crop grain yield (kg/hm^2); *SG* is the ratio of grain to crop in terms of biomass; and I_F is the per capita income that can be improved by straw feeding (Table 2). Local crops included wheat, barley, legume, potatoes, maize, and oilseed rape. *SG* for each crop was calculated according to the literature (Bi et al., 2009; Li et al., 2014a; Peng et al., 2014). *WP* was taken from the county statistical yearbooks, and the Qinghai Province Grass and Livestock Balance Monitoring and Evaluation (Cai et al., 2018).

3.2.3. The N% cultivated grassland demands for income goals in the future

Livestock carrying capacity and income were calculated for *N%* of cultivated grass using the equation below:

$$N\% = \frac{Yt - Ym}{Yc - Ym} \tag{9}$$

where *Yt* is the grassland yield demanded to achieve the target income in 2020, 2025 and 2035; and *Yc* is the yield of cultivated grassland, which is the average of the field experimental data, 13,000 kg/hm^2. The field experiment of cultivation revealed that the mixture of oats and peas had a forage yield of 12752 kg/hm^2 that increased 3645 kg/hm^2 if comparing with the yield of an oat monoculture experiment (Yan, 2010). An experiment at Yushu showed that cultivated grass yield can reach as high as 15,000 kg/hm^2 (Li et al., 2018). Therefore, the value close to the two averages was set as an operational yield of cultivated grassland. The *N%* of cultivated grassland was estimated according to the target income in the future (Table 2).

Table 2
Target N% and annual per capita net income for pastoralism under different scenarios.

Counties	Townships	Actual income (USD$/year)	Theoretical income (USD$/year)	IF (USD$/year)	Cultivated grassland (%)	
					2025	2035
Tongde	Gabasongduo	1193.52	448.35		5.40	22.17
	Tanggu	1130.10	469.92		5.38	24.14
	Bagou	598.70	150.00		23.51	52.60
	Hebei	2950.99	740.59		0.00	9.94
	Xiuma	2836.03	764.49		0.00	8.44
	Total	1584.19	491.55	324.03	3.97	19.76
Zeku	Zequ	796.73	953.70		2.83	14.47
	Ningxiu	1096.74	899.78		4.11	17.26
	Heri	1114.06	916.71		3.43	15.21
	Dohemao	1751.15	1360.21		0.00	6.13
	Maixiu	961.28	912.69		2.92	12.77
	Wangjia	1320.62	1021.89		1.43	10.59
	Xibusa	1022.79	729.98		9.07	26.18
	Total	1116.89	948.18	14.87	2.84	14.20
Henan	Youganing	1914.29	692.11		10.64	39.61
	Ningmute	1030.05	912.18		6.34	29.67
	Toyema	1310.71	641.76		10.55	37.63
	Saierlong	2251.11	1977.54		0.00	11.57
	Kesheng	2768.58	2074.65		0.00	9.14
	Duosong	2219.98	1207.69		2.73	21.88
	Total	1698.52	1051.35		4.50	25.85

$$Yt = \frac{LN \times Sf \times Gt}{Ar \times Ut \times Co \times Ha} \tag{10}$$

where *LN* is the total livestock numbers needed to achieve the target net income; *Sf*, *Gt*, *Ar*, *Ut*, *Co*, *Ha* are the same as in Eqs.(1,3).

$$LN = \frac{Ic \times P}{Sp \times Ch} \tag{11}$$

where *Ic* is the target income per capita; *P* is the predicted population of the pastoral area in 2025 and 2035, according to the Logistic model (Wang et al., 2014); The sale price of sheep unit (Sp) was USD$ 149.3 in both Tongde and Zeku counties, and USD$ 119.4 in Henan. The exchange rate between USD$ and CNY is 6.7.; *Ch* is the same as in Eq.(2).

$$IC = IN \times O \times L + IE - IF \tag{12}$$

where I_N is net income; *O* is operating income of herders (60%); and *L* is proportion of income from animal husbandry by county (Tongde 78%, Zeku 88%, Henan 97%); The data were from the Statistical Yearbook; I_E is productive expenditure; I_F is the per capita income that can be improved by straw feeding; According to the plan for the development of Three-River-Source National Park, the per capita net income (I_N) targets for 2020, 2025, and 2035 were USD$ 1567, USD$ 2090, and USD$ 3731, respectively. Regardless of wages income, transfer net income, or property net income, operating income is projected at about USD$ 940, USD$ 1254, and USD$ 2239 in 2020, 2025 and 2035 respectively.

4. Results

4.1. Present status of income and livestock grazing

The present income is almost completely from livestock grazing, exerting great pressure on grasslands, as shown by the livestock grazing pressure index. The estimated net incomes were USD$ 1584, USD$ 1117, and USD$ 1699, for the three counties of Tongde, Zeku and Henan, respectively, according to actual livestock data in 2018, while their corresponding actual incomes were USD$ 1638, USD$ 1094, and USD$ 1601 according to the statistic yearbook (Fig. 3). Meanwhile, we found that the study region experienced severe overgrazing, from 2.35 to 4.37 times the theoretical carrying capacity (Fig. 4). Although the actual grassland yields were 1459 ± 384 kg/hm^2, 1581 ± 371 kg/hm^2 and 1819 ± 325 kg/hm^2 for the three counties Tongde, Zeku, and Henan, respectively, in the period from 2000 to 2018, their corresponding theoretical stocking rate were only 1.14 SU/hm^2, 1.24 SU/hm^2, and 1.43 SU/hm^2, but the actual stocking rate were 4.98 SU/hm^2, 3.80 SU/hm^2, and 3.36 SU/hm^2 according to the yearbooks, therefore, the livestock grazing pressure index (*Ip*) were 437%, 306%, and 235% for the three counties.

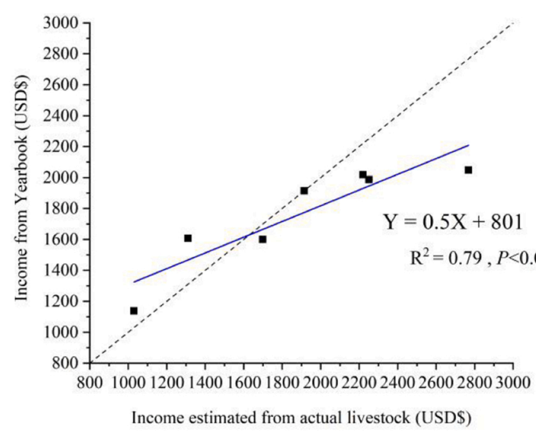

Fig. 3. The estimated income from livestock rate can well capture the income from year-book for each township in Henan County.

The theoretical stocking rate is generally suggested as a measure to manage grassland-based husbandry to prevent grasslands degradation. However, if the livestock would be reduced to the theoretical stocking rate from the present actual level in 2018, the income (I_T) would be significantly decreased and the herders would return to poverty. Specifically, under the theoretical stocking rate, the I_T would decrease to USD$ 492, USD$ 948, and USD$ 1051 for Tongde, Zeku, and Henan respectively, which would be lower by 69%, 40%, and 33% for the three counties than the income target of USD$ 1567 in 2020 (Table 2, Fig. 5b).

The present livestock-based incomes cannot reach the goals for 2025 or 2035. Deficits would be in the range of from 18.7% to 46.6%, compared to the 2025 goal (USD$ 2090), and from 54.5% to 70.1%, compared to the 2035 goal (USD$ 3731) at the township scale for the study area, which will meet great challenges for the two goals. The results suggest it is impossible to realize income goals in 2025 and 2035 if they are only dependent on the natural grassland and worse if those grasslands are managed within their capacity.

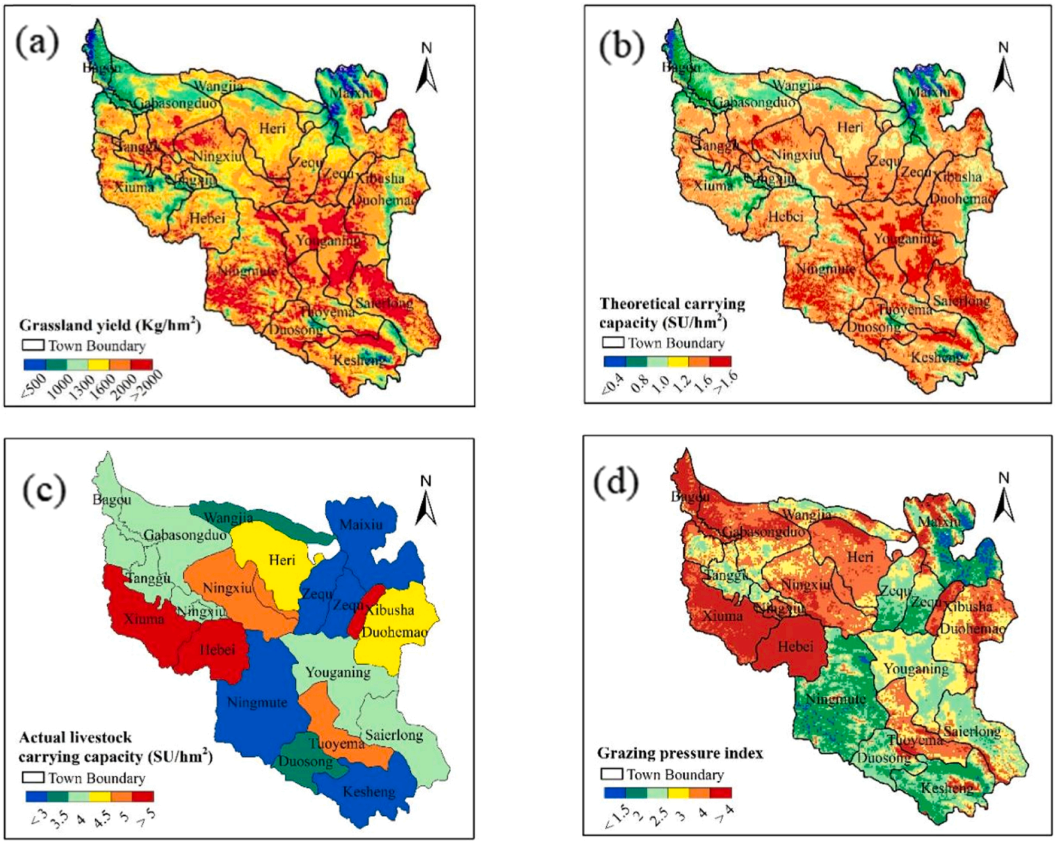

Fig. 4. The grassland yields (a) were estimated with the averaged data in the period from 2000 to 2018 through a remote sensing-based model and the corresponding theoretical carrying capacity (b) calculated from the grassland yield. The actual carrying capacity (c) and the mean grazing pressure index (d) were estimated at township level from the social-economic statistic data for the three counties of Tongde, Zeku, and Henan in eastern Three-River Headwaters Region, Qinghai Province, China.

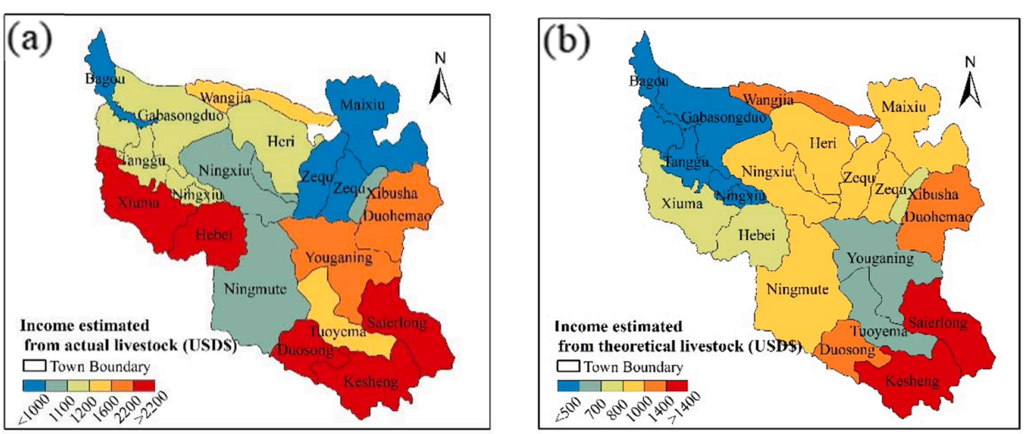

Fig. 5. Net incomes estimated from the (a) actual and (b) theoretical livestocknumbers in 2018 for the three counties of Tongde, Zeku, and Henan at the Township level.

4.2. Possible income increases from extra feeding

Income increases will be very limited even if additional crop straw feeding is used in livestock husbandry. The income increases will be only USD$ 324 and USD$ 15 respectively for Tongde and Zeku, and will be not applicable for Henan without crop cultivation (Table 2).

4.3. Potential income for the N% cultivated grassland

From the perspective of protecting the local ecological environment, an appropriate stocking capacity is required, but from the perspective of improving the lives of local residents, it is not possible to rely on theoretical livestock grazing only. It is necessary to increase the theoretical livestock carrying capacity with cultivated grassland. Developing artificial grassland-based livestock husbandry would be necessary if other industries are unavailable.

The revised N%, the area ratio of cultivated to natural grasslands, was estimated from the forage yields of cultivated grasslands for livestock demands to satisfy the income goals in 2025 and 2035 at the Township level (Fig. 6). For the goal in 2025, the N% will be 3.97%,

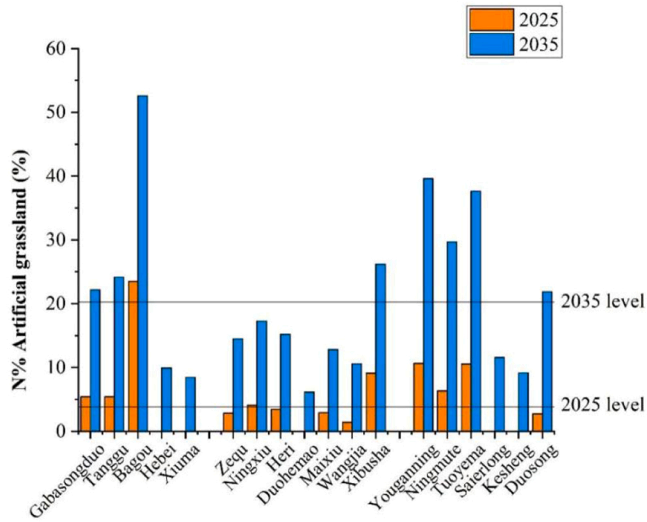

Fig. 6. N% of cultivated grassland required to meet net per capita income targets.

2.84%, and 4.50% for Henan, Zeku, and Tongde, respectively. This means the local herders can realize their income goal of USD$ 2090 in 2025 if about 5% of grasslands is cultivated (Table 2, Fig. 6). Even some Townships, for example, Saierlong, Kesheng, Xiuma, Hebei, Duohemao, can easily realize their goals without developing the cultivated grasslands because those Townships have appropriate climatic conditions, lower population, and higher grass yields, while some Townships will have great difficulties because up to 24% of grasslands is needed for cultivation to meet the targets in 2025.

However, local herders will face great challenges to realize the targets in 2035, because cultivated grasslands proportion above 14% will be demanded. Specifically, the N% will be 19.76%, 14.20%, and 25.85% in Henan, Zeku and Tongde, respectively, on the county scale and will vary greatly from 6% to 53% on the Township scale.

5. Discussion

5.1. Income sources

This study has many implications for realizing sustainable development goals on the Qinghai-Tibetan Plateau, though the various concepts and models were proposed for a win-win goal of rehabilitating grassland while improving livelihoods (Fang et al., 2018; Zhao et al., 2018; Kemp, 2020). The grasslands were seriously overgrazed, from 2.35 to 4.37 times the theoretical carrying capacity in those areas (Fig. 4), which was reported previously (Harris et al., 2016; Shao and Fan, 2018; Kemp et al., 2020). However, the net income averaged only \$1444 in 2018, which is lower than the national rural average (\$2182) and the province rural average (\$1551) according to Yearbook of Qinghai Province. Of the herdsmen's net income, operating income accounted for 60%, on a regional means basis. Livestock grazing income, however, is almost 97% of operating income in Henan (Table 1). Maybe, there are other income sources that are not accounted for here. For example, Tibetan medicine (22.4%), subsidies (22.3%), and others sources of income (17.7%) along with livestock income of 36.2% are noted in the near counties of Maduo, Maqin and Jiuzhi in the Three-River Headwaters region (Sheng et al., 2019). This means the dominant income source is almost completely attributed to the natural grassland-based livestock husbandry, though other income contributed substantially to decreasing income pressure. Local herders need to meet great challenges in order to accomplish income goals set for 2025 and 2035. Therefore, utilizing the N% approach for proposing natural grasslands and cropland proportions seems to be a viable option for sustainability planning.

5.2. Feasibility of techniques, economic and ecologic costs

This approach is feasible on techniques, economic and ecologic costs to aid decision-making for cultivated grassland-based livestock husbandry. Technically, cultivated grassland has been widely considered in the ecological restoration of the Qinghai-Tibetan plateau (Zhao, 2011; Dong et al., 2020), though it is in a very fragile environmental condition (Shao and Fan, 2018). Through a recent investigation using remote sensing methods in the eastern Three-River Headwaters Region, the land cultivated for fodder crop was determined to be less than 1% of the grasslands area (Ge Li et al., in review). Considering the income targets for 2035, we suggested to use 19.76%, 14.20%, and 25.85% of grassland or cropland in Henan, Zeku and Tongde to develop fodder cultivation, which was feasible for those regions considering their climatic conditions with temperature ranges and enough annual accumulative precipitation (Table 1). The forage from the cultivated grassland, such as *Gramineae*, *Leguminosae*, or their mixes, has higher quality and higher yield and the yield can reach 2.7–12.1 times than natural grassland (Li et al., 2016; Shen et al., 2016; Gao et al., 2019).

The ecologic cost is another concern for development decisions that include cultivated grasslands. Cultivation of grasslands, as land cover and land use changes (LUCC), generally results in increasing soil erosion, decreasing biodiversity, even returning to degradation (Klein et al., 2013; Fatichi et al., 2014), which can be quantified through its ecosystem services. According to Jiang et al. (2020), the ecologic value of a meadow was estimated at 5751.57 \$/ha, while the cropland was only 2017.82 \$/ha. While data are largely unavailable for cultivated grassland, the ecologic value of cropland was assumed for cultivated grassland. The total ecologic value will be decreased 12.83%, 9.22% and 16.78% if the cultivated grassland would be developed on the meadow grassland of 19.76%, 14.20% and 25.85% and only considering local grassland resources and including Subsidy and Incentive System (SISGC) (Table 2). This analysis indicated there is inevitable trade-offs between economic and ecologic value, but on the global scale, some appropriate ecosystem management techniques may avoid trade-offs and convert this relationship to synergies (Wu et al., 2017; Bengtsson et al., 2019; Xu et al., 2019).

But the negative effects, on the other hand, only happen on an area no more than one quartile of the total grasslands. In other words, more than 3/4 of grasslands could be conserved and could be positively improved in this way. It may be described as "conserve big area while utilizing small grasslands," that is, take advantage of small areas with good hydrothermal conditions to increase income, and of large areas of grassland for conservation, (Wei, 2010; Fang et al., 2018). This approach has recently been implemented in parts of Mongolia (Liu et al., 2018; Wu et al., 2019; Zhao et al., 2019; Huq et al., 2020).

5.3. Disturbances from climate change

Climate change and its impact on husbandry is expected to exert profound impacts on biodiversity and ecosystem services (Gherardi and Sala, 2015; Hruska et al., 2017a), which imperils sustainability of grassland husbandry. Although grassland livestock carrying capacity fluctuates due to climatic influences (Wang et al., 2011b; Gherardi and Sala, 2015; Behrendt et al., 2016, 2020; Hruska et al., 2017a), cultivated grassland needs to maintain a relatively stable area in order to implement management measures consistently over time to maintain grass production (Li et al., 2016); therefore, we used static livestock carrying capacity as the basis for income calculation in this study as did Hu et al. (2019). On the other hand, the approach proposed in this paper is one strategy that may be explored by scientists and governments to contribute to climate change adaptation planning to realize sustainable development goals.

5.4. The policy implications

Based on these findings, it is suggested that the government consider developing a GLiH pilot project under the premise of "ecological priority" (Ma et al., 2016; Xu et al., 2020; Zhang et al., 2020). Specifically, industry should be facilitated to intensively solve the shortage of high-quality forage by a standardized and large-scale forage production system. When the policy is extended to the whole Qinghai-Tibet Plateau region in the future, the principle of ecological priority should still be followed, with no production activities in protected areas, and the forage industry can only be built in the surrounding areas by considering suitable accumulated temperature, total precipitation, and soil fertility, which avoids conflicts due to water resource risks under global climate change projections.

Animal husbandry cooperatives should be promoted to develop GLiH. Traditional animal husbandry still is a kind of smallholders' economy with decentralized management, which leads to a lower degree of mechanization, lower animal production efficiency, and lower capability to mitigate and adapt to climate change, especially extreme climate events. The cooperative economy could solve those problems as an organized company of some herder families utilize grassland together with less labor inputs. And this is considered being suitable for the reform of land use rights (Zhang, 2014; Bao and Shi, 2020; Dong, 2020). These cooperative companies, however, should be managed by local governments because these companies should be not for-profit, but rather public benefit companies that aim to enhance the livelihoods of local pastoralists, though external companies and investments are encouraged.

The implementation of N% needs to consider many factors. Spatial heterogeneity of grassland vegetation distribution, and inter-annual variability in climate changes may affect N% and its implementation. Some specific detailed factors such as current artificial grassland development status, specific livestock numbers and grazing methods (winter and summer pasture rotation time and grazing numbers, etc.) need to be further considered in practice. Artificial grassland can be identified by satellite remote sensing (Yang et al., 2021), but the quantification of rotation time and grazing quantity etc. is more difficult, and further ground survey is needed for analysis. In addition, there are many technical details to be considered for the establishment of artificial grassland, such as climate, soil, and seeding methods, which need to be carefully considered based upon "*Technical specifications for artificial grass planting* "(DB63/T 391–2018)(Qinghai Provincial Market Supervision Administration, 2018), but need to be adjusted and improved according to local conditions.

The introduction of new policies yet may affect N%. Recently, the Chinese government suggested to implement the valuation of ecological products (Xinhua News Agency, 2021). It accounts for the value of ecological products and then returns them to herders in the form of ecological compensation, then the net transfer income will further increase, which can reduce the proportion of operating income and reduce the proportion of income that herders rely on grazing, which will further reduce N%. However, as a deeper consideration beyond the study of this paper, after the herders' livelihoods are completely solved through the series of transfer payments, if herders no longer need to graze their livestock, the traditional pastoral culture becomes a concept without physical support. Therefore, exogenous subsidies are only supplementary, but the key is to enhance the development capacity of herders themselves, develop artificial grassland based on N%, and maintain the traditional grazing culture, so that herders can improve their income and protects the sustainability of the ecological environment.

6. Conclusions

A win-win approach is being explored worldwide to accomplish poverty alleviation and ecosystem function protection. We suggest to develop cultivated grassland-based livestock husbandry through utilizing 5–14% of grassland or cropland in order to realize the goals of natural grasslands rehabilitation, realizing the income targets for pastoralists in 2035 in the study area, which is part of the development plan for Three-River-Source National Park in the Qinghai-Tibetan plateau, China. However, many factors, such as the organization of a cooperative organization, investments from local or external sources, land policies on rent, and their impacts on herders' income, need further investigation and planning in detail as it is applied in practice in the future. This study provided a top-down method to quantify the amount of cultivated grassland demanded to realize these win-win goals. Methodologically, it can be applied to predict and analyze income changes under different climate scenarios in the future. And it also can be applied now to make informed policies to increase probability of sustainable development aimed to protect the ecological and economic values of grasslands worldwide.

Acknowledgements

This work was supported by the Chinese Academy of Sciences Special Project on Strategic Pioneering Science and Technology (XDA23100202), The Second Tibetan Plateau Scientific Expedition and Research (STEP) program (2019QZKK0302), Chinese Academy of Sciences and Qinghai Province Joint Program (LHZX-2020-07) and National Natural Science Foundation of China (31971507). We thank the contributions of the Editor and anonymous reviewers for their comments and suggestions.

References

Bao, Z., Shi, T., 2020. Urbanization and ecological governance in pastoral areas. Soc. Sci. China 146–162, 207.

Behrendt, K., Cacho, O., Scott, J.M., Jones, R., 2016. Using seasonal stochastic dynamic programming to identify optimal management decisions that achieve maximum economic sustainable yields from grasslands under climate risk. Agric. Syst. 145, 13–23.

Behrendt, K., Takahashi, T., Kemp, D.R., Han, G., Li, Z., Wang, Z., Badgery, W., Liu, H., 2020. Modelling Chinese grassland systems to improve herder livelihoods and grassland sustainability. Rangel. J. 42, 329–338.

Bengtsson, J., Bullock, J.M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H.G., Lindborg, R., 2019. Grasslands—more important for ecosystem services than you might think. Ecosphere 10, e02582.

Bi, Y., Gao, C., Wang, Y., Li, B., 2009. Estimated quantity of straw resources in China. Trans. Chin. Soc. Agric. Eng. 25, 211–217.

Bilgen, S., Sarıkaya, İ., 2015. Exergy for environment, ecology and sustainable development. Renew. Sustain. Energy Rev. 51, 1115–1131.

Bryan, B.A., Gao, L., Ye, Y., Sun, X., Connor, J.D., Crossman, N.D., Stafford-Smith, M., Wu, J., He, C., Yu, D., Liu, Z., Li, A., Huang, Q., Ren, H., Deng, X., Zheng, H., Niu, J., Han, G., Hou, X., 2018. China's response to a national land-system sustainability emergency. Nature 559, 193–204.

Cai, F., Wang, X., Jing, X., Su, Y., Bao, H., 2018. A study on remote sensing of grass and animal balance monitoring and evaluation in Qinghai Province. China Agric. Inf. 30, 92–104.

Chen, F., Zhang, J., Liu, J., Cao, X., Hou, J., Zhu, L., Xu, X., Liu, X., Wang, M., Wu, D., Huang, L., Zeng, T., Zhang, S., Huang, W., Zhang, X., Yang, K., 2020. Climate change, vegetation history, and landscape responses on the Tibetan Plateau during the Holocene: a comprehensive review. Quat. Sci. Rev. 243.

Cheng, D., Peili, S., Xianzhou, Z., Ning, Z., Xi, C., Shoubao, G., Wanrui, Z., 2017. The rangeland livestock carrying capacity and stocking rate in the Kailash sacred landscape in China. J. Resour. Ecol. 8, 551–558.

Dong, S. 2020. The construction of grassland natural park to promote the coordinated development of protection and utilization.

Dong, S., Shang, Z., Gao, J., Boone, R.B., 2020. Enhancing sustainability of grassland ecosystems through ecological restoration and grazing management in an era of climate change on Qinghai-Tibetan Plateau. Agric. Ecosyst. Environ. 287.

Du, S.Q., Cheng, X.T., Huang, Q.X., Chen, R.S., Ward, P.J., Aerts, J., 2019. Brief communication: rethinking the 1998 China floods to prepare for a nonstationary future. Nat. Hazards Earth Syst. Sci. 19, 715–719.

Fan, J.-W., Shao, Q.-Q., Liu, J.-Y., Wang, J.-B., Harris, W., Chen, Z.-Q., Zhong, H.-P., Xu, X.-L., Liu, R.-G., 2010. Assessment of effects of climate change and grazing activity on grassland yield in the three rivers headwaters region of Qinghai-Tibet Plateau, China. Environ. Monit. Assess. 170, 571–584.

Fan, J., Shao, Q., Wang, J., Chen, Z., Zhong, H., 2011. Temporal and spatial dynamics analysis of livestock carrying pressure in grasslands of the three-river headwaters. Chin. J. Grassl. 33, 64–72.

Fang, J., Jing, H., Zhang, W., Gao, S., Duan, Z., Wang, H., Zhong, J., Pan, Q., Zhao, K., Bai, W., Li, L., Bai, Y., Jiang, G., Huang, J., Huang, Z., 2018. The concept of "grass-

based livestock husbandry" and its practice in Hulun Buir, Inner Mongolia. Chin. Sci. Bull. 63, 1619–1631.
Fatichi, S., Zeeman, M.J., Fuhrer, J., Burlando, P., 2014. Ecohydrological effects of management on subalpine grasslands: from local to catchment scale. Water Resour. Res. 50, 148–164.
Gao, S., Hu, Z., Han, Y., Liu, Z., Pan, Q., Duan, R., Zhong, J., Jing, H., 2019. The role and potential of ecological grassland husbandry in precise poverty alleviation in china–exploration of science and technology poverty alleviation practices and models at the institute of botany. Chin. Acad. Sci. Bull. 34, 223–230. +126.
Gherardi, L.A., Sala, O.E., 2015. Enhanced precipitation variability decreases grass- and increases shrub-productivity. Proc. Natl. Acad. Sci. USA 112, 12735–12740.
Golluscio, R.A., Bottaro, H.S., Oesterheld, M., 2015. Controls of carrying capacity: degradation, primary production, and forage quality effects in a patagonian Steppe. Rangel. Ecol. Manag. 68, 266–275.
Gongbuzeren, L., Huntsinger, Li, W., 2018. Rebuilding pastoral social-ecological resilience on the Qinghai-Tibetan Plateau in response to changes in policy, economics, and climate. Ecol. Soc. 23.
Guo, B., Wang, S., Wang, M.-T., 2020. Spatio-temporal variation of NPP from 1999 to 2015 in Zoige grassland wetland. China Ying yong sheng tai xue bao = J. Appl. Ecol. 31, 424–432.
Harris, R.B., Samberg, L.H., Yeh, E.T., Smith, A.T., Wenying, W., Junbang, W., Gaerrang, Bedunah, t l D.J., 2016. Rangeland responses to pastoralists' grazing management on a Tibetan steppe grassland, Qinghai Province, China. Rangel. J. 38.
Hruska, T., Huntsinger, L., Brunson, M., Li, W., Marshall, N., Oviedo, J., Whitcomb, H., 2017a. Rangel. Soc. Syst. 263–302.
Hruska, T., Huntsinger, L., Brunson, M., Li, W., Marshall, N., Oviedo, J.L., Whitcomb, H., 2017b. Rangelands as social–ecological systems. In: Briske, D.D. (Ed.), Rangeland Systems: Processes, Management and Challenges. Springer International Publishing, Cham, pp. 263–302.
Hu, Y., Huang, J., Hou, L., 2019. Impacts of the grassland ecological compensation policy on household livestock production in China: an empirical study in inner Mongolia. Ecol. Econ. 161, 248–256.
Hua, L.M., Squires, V.R., 2015. Managing China's pastoral lands: current problems and future prospects. Land Use Policy 43, 129–137.
Huang, L., Shao, Q.Q., Liu, J.Y., Lu, Q.S., 2018. Improving ecological conservation and restoration through payment for ecosystem services in Northeastern Tibetan Plateau, China. Ecosyst. Serv. 31, 181–193.
Huq, N., Pedroso, R., Bruns, A., Ribbe, L., Huq, S., 2020. Changing dynamics of livelihood dependence on ecosystem services at temporal and spatial scales: an assessment in the southern wetland areas of Bangladesh. Ecol. Indic. 110, 105855.
Jiang, W., Lü, Y., Liu, Y., Gao, W., 2020. Ecosystem service value of the Qinghai-Tibet Plateau significantly increased during 25 years. Ecosyst. Serv. 44, 101146, 101146.
Kemp, D., 2020. Sustainable Chinese Grasslands. Australian Centre for International Agricultural Research,, Canberra.
Kemp, D.R., Behrendt, K., Badgery, W.B., Han, G.D., Li, P., Zhang, Y., Wu, J., Hou, F.J., 2020. Chinese degraded grasslands – pathways for sustainability. Rangel. J. 42, 339–346.
Klein, T., Holzkaemper, A., Calanca, P., Seppelt, R., Fuhrer, J., 2013. Adapting agricultural land management to climate change: a regional multi-objective optimization approach. Landsc. Ecol. 28, 2029–2047.
Lee, H. 2020. Statement on the 30th anniversary of the IPCC First Assessment Report. IPCC newsroom.
Li, G., Sun, W., Zhang, H., Gao, C., 2014a. Remote sensing monitoring of livestock load balance in grassland on the Tibetan Plateau based on straw feeding. Trans. Chin. Soc. Agric. Eng. 30, 200–211.
Li, G., Zhang, Y., Ga, M., He, S., Song, R., 2018. Yushu city state farm grass-livestock balance survey. Chin. Qinghai J. Anim. Vet. Sci. 48, 52–53.
Li, L., Lu, P., Gu, X., Mao, X., Gao, S., Zhang, Y., 2016. Artificial grassland construction principles and production paradigms. Chin. Sci. Bull. 61, 193–200.
Li, Q., Hu, L., Chen, D., He, F., Chen, X., Cao, Y., Xu, S., Zhao, L., Zhao, X., 2019. Practice of regional function optimization in Sanjiangyuan national park based on N%. Acta Theriol. Sin. 39, 347–359.
Li, X.L., Perry, G.L.W., Brierley, G., Sun, H.Q., Li, C.H., Lu, G.X., 2014b. Quantitative assessment of degradation classifications for degraded alpine meadows (Heitutan), sanjiangyuan, Western China. Land Degrad. Dev. 25, 417–427.
Liu, J., Tian, H., Liu, M., Zhuang, D., Melillo, J.M., Zhang, Z., 2005. China's changing landscape during the 1990s: large-scale land transformations estimated with satellite data. Geophys. Res. Lett. 32, L02405.
Liu, J., Zhang, Z., Xu, X., Kuang, W., Zhou, W., Zhang, S., Li, R., Yan, C., Yu, D., Wu, S., 2010a. Spatial patterns and driving forces of land use change in China during the early 21st century. J. Geogr. Sci. 20, 483–494.
Liu, J., Zhang, Z., Zhuang, D., Wang, Y., Zhou, W., Zhang, S., Li, R., Jiang, N., Wu, S., 2003. A study on the spatial-temporal dynamic changes of land-use and driving forces analyses of China in the 1990s. Geogr. Res. 22, 1–12.
Liu, M., Dries, L., Huang, J., Min, S., Tang, J., 2019. The impacts of the eco-environmental policy on grassland degradation and livestock production in Inner Mongolia, China: An empirical analysis based on the simultaneous equation model. Land Use Policy 88, 104167.
Liu, R., Chen, J.M., Liu, J., Deng, F., Sun, R., 2007. Application of a new leaf area index algorithm to China's landmass using MODIS data for carbon cycle research. J. Environ. Manag. 85, 649–658.
Liu, X., Feng, Q., Liang, T., Long, R., 2010b. A study of the spatio-temporal dynamic balance between pasture productivity and livestock carrying capacity in the Gannan rangeland. Chin. J. Grassl. 32, 99–106.
Liu, X., Tang, H., Yin, C., 2018. A Strategic Study on Transforming Agricultural Development and Building Beautiful Villages. Science Press,, Beijing.
Ma, F., Du, G., Yang, S., Feng, P., 2016. The current situation and future development trend of grassland animal husbandry. Agric. Econ. 66–67.
Meshesha, D.T., Moahmmed, M., Yosuf, D., 2019. Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia. Ecol. Evol. 9, 13309–13319.
MOA. 2015. Calculation propercarrying capacityof rangelands. Ministry of Agriculture of the People's Republic of China.
NDRC. 2018. The master plan of the three rivers source national park. National Development and Reform Commission (NDRC).
NFGA. 2020. Effect and Suggestions on the Incentive Policy of Grassland Ecological Protection Subsidy. National Forestry and Grassland Administration,.
O'Reagain, P., Scanlan, J., Hunt, L., Cowley, R., Walsh, D., 2014. Sustainable grazing management for temporal and spatial variability in north Australian rangelands – a synthesis of the latest evidence and recommendations. Rangel. J. 36.
Ouyang, Z., Du, A., Xu, W., 2020a. Research on China's protected area system classification. Acta Ecol. Sin. 40, 7207–7215.
Ouyang, Z., Ouyang, Z., Song, C., Song, C., Zheng, H., Zheng, H., Polasky, S., Polasky, S., Xiao, Y., Xiao, Y., Bateman, I.J., Liu, J., Liu, J., Ruckelshaus, M., Shi, F., Xiao, Y., Xu, W., Xu, W., Zou, Z., Zou, Z., Daily, G.C., Daily, G.C., 2020b. Using gross ecosystem product (GEP) to value nature in decision making. Proc. Natl. Acad. Sci. USA 117, 14593–14601.
Peng, C., Luo, H., Kong, J., 2014. Progress in the estimation and utilization of crop straw resources in China. Chin. J. Agric. Resour. Reg. Plan. 35, 14–20.
Qinghai Provincial Market Supervision Administration. 2018. Technical specifications for artificial grass planting.
Rees, W.E., 1996. Revisiting carrying capacity: area-based indicators of sustainability. Popul. Environ. 17, 195–215.
Ren, J., 2013. China's traditional agricultural structure can not be changed - the hidden worries after nine consecutive increases in food. Acta Pratacult. Sin. 22, 1–5.
Ren, J., Xu, G., Li, X., Lin, H., Tang, Z., 2016. Trajectory and prospect of China's prataculture. Chin. Sci. Bull. 61, 178–192.
Shao, Q., Cao, W., Fan, J., Huang, L., Xu, X., 2017. Effects of an ecological conservation and restoration project in the Three-River Source Region, China. J. Geogr. Sci. 27, 183–204.
Shao, Q., and J. Fan. 2018. Monitoring and Evaluation of Ecological Benefits of Ecological Protection and Construction Projects in the Three-River Source Region, China, Beijing.
Shen, H., Zhu, Y., Zhao, X., Geng, X., Gao, S., Fang, J., 2016. Analysis of current grassland resources in China. Chin. Sci. Bull. 61, 139–154.
Sheng, W., Zhen, L., Xiao, Y., Hu, Y., 2019. Ecological and socioeconomic effects of ecological restoration in China's three rivers source region. Sci. Total Environ. 650, 2307–2313.
Sun, M.Y., Li, X.H., Yang, R.J., Zhang, Y., Zhang, L., Song, Z.W., Liu, Q., Zhao, D., 2020. Comprehensive partitions and different strategies based on ecological security and economic development in Guizhou Province, China. J. Clean. Prod. 274, 14.
Sun, W., Shao, Q., Liu, J., Xiao, T., 2011. The variation characteristics of soil organic carbon of typical alpine slope grasslands and its influencing factors in the "three-river headwaters" region. J. Nat. Resour. 26, 2072–2087.
Tian, M., Fang, S., 2017. A review of national park selection criteria system in China: a case study of 9 national park experimental areas. World For. Res. 30, 62–68.
Wang, J., 2021. In: Wang, J. (Ed.), Dataset of Annual Net Primary Productivity of Vegetation in Three-Rivers Headwater Region, Qinghai Province, 2000-2018. National Ecosystem Science Data Center, Beijing.
Wang, J., Liu, J., Cao, M., Liu, Y., Yu, G., Li, G., Qi, S., Li, K., 2011a. Modelling carbon fluxes of different forests by coupling a remote-sensing model with an ecosystem process model. Int. J. Remote Sens. 32, 6539–6567.
Wang, J., Liu, J., Shao, Q., Liu, R., Fan, J., Chen, Z., 2009. Spatial-Temporal patterns of net primaryproductivity for 1988-2004 based on GLOPEM-CEVSA model in the "Three-River Headwaters " region of Qinghai province, China. Chin. J. Plant Ecol. 33, 254–269.
Wang, L., Yang, Y., Feng, Z., You, Z., 2014. Prediction of China's population in 2020 and 2030 on county scale. Geogr. Res. 33, 310–322.
Wang, Z., Jiao, S., Han, G., Zhao, M., Willms, W.D., Hao, X., Wang, J. a, Din, H., Havstad, K.M., 2011b. Impact of stocking rate and rainfall on sheep performance in a desert steppe. Rangel. Ecol. Manag. 64, 249–256.
Wei, J., 2010. grassland Resource Science. China Agriculture Press, Beijing.
Wu, J., Zhao, Y., Yu, C., Luo, L., Pan, Y., 2017. Land management influences trade-offs and the total supply of ecosystem services in alpine grassland in Tibet, China. J. Environ. Manag. 193, 70–78.
Wu, T., Wu, Y., Wang, D., Lin, H., 2019. A study on the impact of livelihood capital on the livelihood strategies of pastoralist households in the Three-River Headwaters region. Acta Pratacult. Sin. 28, 12–21.
Xu, M., 2014. A review of grassland carrying capacity:perspective and dilemma for research in China on"forage-livestock balance". Acta Pratacult. Sin. 23, 321–329.
Xu, T., Zhao, X., Geng, Y., Wang, X., Mao, S., Xu, S., 2020. Key technologies and optimization model for ecological protection and grass-based livestock husbandry in the source region of the Yellow River. Resour. Sci. 42, 508–516.
Xu, X., J. Liu, S. Zhang, R. Li, C. Yan, and S. Wu. 2018. China's Multi-Period Land Use Land Cover Remote Sensing Monitoring Data Set (CNLUCC) Resource and Environment Data Cloud Platform, Beijing.
Xu, Y., Dong, S., Gao, X., Yang, M., Li, S., Shen, H., Xiao, J., Han, Y., Zhang, J., Li, Y., Zhi, Y., Yang, Y., Liu, S., Dong, Q., Zhou, H., Stufkens, P., 2019. Trade-offs and cost-benefit of ecosystem services of revegetated degraded alpine meadows over time on the Qinghai-Tibetan Plateau. Agric. Ecosyst. Environ. 279, 130–138.

Xinhua News Agency. 2021. General Office of the Central Committee of the Communist Party of China General Office of the State Council issued the Opinions on Establishing a Sound Mechanism for Realizing the Value of Ecological Products.
Yan, M., 2010. Experimental mixed seeding of annual cultivated grasslands in the ecological migrant community of three-river headwaters. Chin. Qinghai J. Anim. Vet. Sci. 40, 9–10.
Yang, T., Zhang, G., Li, Y., Fan, J., Sun, D., Wang, J., Di, Y., You, N., Liu, R., Zhang, Q., Doughty, R.B., 2021. Satellite observed rapid green fodder expansion in northeastern Tibetan Plateau from 2010 to 2019. Int. J. Appl. Earth Obs. Geoinf. 102, 102394.
Yang, Y., Wang, J., Liu, P., Lu, G., Li, Y., 2019. Climatic changes dominant interannual trend in net primary productivity of alpine vulnerable ecosystems. J. Resour. Ecol. 10, 379–388.
Yin, Y., Hou, Y., Langford, C., Bai, H., Hou, X., 2019. Herder stocking rate and household income under the grassland ecological protection award policy in northern China. Land Use Policy 82, 120–129.
Zang, Y., Liu, Y., Yang, Y., Woods, M., Fois, F., 2020. Rural decline or restructuring? Implications for sustainability transitions in rural China. Land Use Policy 94, 104531.
Zhang, H., Fan, J., Cao, W., Zhong, H., Harris, W., Gong, G., Zhang, Y., 2018a. Changes in multiple ecosystem services between 2000 and 2013 and their driving factors in the Grazing Withdrawal Program, China. Ecol. Eng. 116, 67–79.
Zhang, H., Fan, J., Shao, Q., 2015. Land use/land cover change in the grassland restoration program areas in China, 2000-2010. Prog. Geogr. 34, 840–853.
Zhang, H., Fan, J., Wang, J., Cao, W., Harris, W., 2018b. Spatial and temporal variability of grassland yield and its response to climate change and anthropogenic activities on the Tibetan Plateau from 1988 to 2013. Ecol. Indic. 95, 141–151.
Zhang, K., Sun, X., Jin, Y., Liu, J., Wang, R., Zhang, S., 2020. Development models matter to the mutual growth of ecosystem services and household incomes in developing rural neighborhoods. Ecol. Indic. 115.
Zhang, Y.J., Zhang, X.Q., Wang, X.Y., Liu, N., Kan, H.M., 2014. Establishing the carrying capacity of the grasslands of China: a review. Rangel. J. 36, 1–9.
Zhang, Z. 2014. The Research on Performance Evaluation of Qinghai Ecological Livestock Husbandry Cooperative. master. Qinghai university.
Zhao, M., Zheng, S., Wang, Z., Han, G., 2014. Sustainable Grassland Management. Science Press, Beijing.
Zhao, X., 2011. Ecosystem Restoration and Sustainable Management of Degraded Grassland in Sanjiangyuan Area. Science Press, Beijing.
Zhao, X., Zhao, L., Li, Q., Chen, H., Zhou, H., Xu, S., Dong, Q., Wu, G., He, Y., 2018. Using balance of seasonal herbage supply and demand to inform sustainable grassland management on the Qinghai–Tibetan Plateau. Front. Agr. Sci. Eng. 5, 1–8.
Zhao, Z., Wang, G., Chen, J., Wang, J., Zhang, Y., 2019. Assessment of climate change adaptation measures on the income of herders in a pastoral region. J. Clean. Prod. 208, 728–735.
Zhou, X., 2001. The Kobresia Meadow in China. Science Press, Beijing.