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Grassland Degradation on the Qinghai-Tibetan Plateau: Reevaluation of Causative Factors☆

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A B S T R A C T

In light of Harris (2010) finding insufficient evidence to assert a causal linkage between any of the seven previously proposed causative factors and grassland degradation on the Qinghai-Tibetan Plateau (QTP), more recent empirical studies on QTP grassland degradation were explored to ascertain whether, in fact, these factors are casually linked to grassland degradation. The mischaracterization of the underlying causes of grassland degradation among policymakers has and continues to be an obstacle to sustainable regional grassland management practices. Accumulating evidence suggests that privatization and sedentarization, small mammals, climate change, harsh environments, fragile soils, and overgrazing contribute to grassland degradation. However, neither obsolete livestock husbandry methods nor the recent conversion of rangelands to agriculture had a meaningful influence. Estimates of the total area of degraded grasslands and the establishment of grassland degradation criteria have not been properly addressed in the literature. Both omissions constitute the basis for investigating the causes of grassland degradation across the QTP and the adoption of measures to manage these grasslands sustainably.

INTRODUCTION

Grassland degradation is a worldwide ecological problem (Harris, 2010; Wu et al., 2014; Lu et al., 2017), posing a major global threat to ecosystem functions and basic services (Lehnert et al., 2014). Accordingly, it can lead to 1) greater soil erosion and nutrient loss (Cao et al., 2013a; Huang et al., 2014; Li et al., 2014; He and Richards, 2017; Lu et al., 2017; Li et al., 2018a), 2) increasingly adverse effects on pastoralists' livelihoods, food security, and way of life (Harris et al., 2016), and 3) greater æolian erosion and dust in the atmosphere (Huang et al., 2017).

Harboring a grassland area of ≈ 1.5 million km^2, the Qinghai-Tibetan Plateau (QTP) plays an important role in climate regulation and water resource security in Asia, while also contributing to global carbon cycling and the protection of unique species (Foggin, 2008; Li et al., 2013a; Cai et al., 2015; Cao et al., 2018a). In the late 1990s, the impacts of grassland degradation drew increasing attention from Chinese scientists and policymakers, when drought in the Yellow River basin brought more frequent dust storms and sandstorms from western China and Yangtze River floods adversely affected the health and economic well-being of eastern China's population (Harris, 2010).

DETERMINING CAUSES OF DEGRADATION: SOURCES OF COMPLEXITY AND CONFUSION

Area of Grassland Degradation on the QTP

In the past, most Chinese studies stated that ≈ 90% of QTP's grasslands were degraded to some extent, although the lack of documented surveys prevented a firm confirmation of these estimates (Harris, 2010). At present, some studies still claim that most grasslands on the QTP exhibit high levels of degradation (e.g., Ren et al., 2013a; Wang et al., 2015a), whereas other studies have

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suggested figures of 50% (Dong et al., 2013; Wu et al., 2014), 40% (Cai et al., 2015; Wang et al., 2016a), and even as low as 33% (Li et al., 2013b) when estimating grassland degradation through vegetative cover derived from remote sensing. However, obtaining an accurate quantitative measure of vegetative cover remains a common and recurring problem (Wang et al., 2012; Lehnert et al., 2015). Moreover, Liu et al. (2015a) pointed out that grassland degradation can occur without any obvious reduction in vegetative cover.

Remote-sensing observations presently employed in assessing grassland degradation cannot provide adequate proxies for nutrient and water availability and therefore cannot serve to distinguish whether low plant cover is the result of high grazing pressure or a consequence of local site conditions. Accordingly, chlorophyll concentration could be considered as an indicator of plant health, as it can help to distinguish between the effects of grazing and varying site conditions (Lehnert et al., 2015).

Criteria for Degradation

Standardizing the measurements of grassland degradation is critical to assessing the status and extent of grassland degradation (Wang et al., 2015b). As Harris (2010) pointed out, most Chinese investigators assumed that a reduction of vegetative production or primary productivity represents degradation and equate the level of degradation with the level of reduction in production. Accordingly, 20–30%, 30–50%, and > 50% declines in productivity were deemed to represent light, moderate, and heavy degradation, respectively. However, such criteria can be considered imprecise because no baseline has been set to relativize the reduction. Grazing itself acts to reduce the biomass relative to a nongrazed condition, but the presence of livestock in an area may have precluded it from being assigned a "nondegraded" status (Harris, 2010). However, in the studies of Wen et al. (2013) and Wu et al. (2014), a nondegraded baseline (free grazing) was set, and four further degrees of grassland degradation were based thereon: light, moderate, heavy, and severe. No significant differences in biomass, coverage, or percentage of high-quality herbage were found between heavily and moderately degraded grassland. Again, this suggests that these criteria may not reliably assess the extent of grassland degradation. Furthermore, there is considerable overlap between the criteria that are used to differentiate degradation types, and thus a careful definition of degradation classes and appraisal of the underlying causes of degradation are key issues in the design and implementation of rehabilitation measures in these rangelands (Li et al., 2012). Despite this, many Chinese studies continue to use the criteria developed by (Ma et al. 2002) to quantify the level of grassland degradation (**Appendix 1**).

Table 1
Grassland degradation criteria for the Qinghai-Tibetan Plateau employed by researchers.

Studies	Criterion
Wu and Yang, 2011; Wang et al., 2013; Liu et al., 2015a; Wu et al., 2015a; Peng et al., 2017; Shao et al., 2017; Wu et al., 2017a; He and Richards, 2017	Dominant species
Ren et al., 2013b	Periphyton biomass
Li et al., 2015a	Abundance of palatable grasses
Peng et al., 2015; Sun et al., 2015	Number of rodent holes
Dong et al., 2015; Chai et al., 2017	Stocking rates
Li et al., 2015b	Percentages of bare ground
Li et al., 2017	Vector analysis approach
Wang et al., 2017	Distance from camps
Li et al., 2018a	Different fencing time

Besides the common criteria for degradation cited earlier, further criteria of greater or lesser efficiency have also been used (see Table 1). For example, Yan and Lu (2015) found that the Simpson dominance index did not differ between periods of grazing exclusion (6–8 yr) and periods of free grazing. Tang et al. (2015) and Li et al. (2015a) found that the two dominant species (*Kobresia pygmaea* [C.B.Clarke] C.B.Clarke and *Kobresia humilis* [C.A.Mey. ex Trautv.] Serg.) and the diversity of alpine meadow and alpine steppe were barely altered along gradients of degradation and that physiological desiccation (decline in soil water content and retention) was an important driving factor in nonequilibrium vegetation transitions.

POSSIBLE CAUSES OF GRASSLAND DEGRADATION ON THE QTP: CURRENT STATE OF KNOWLEDGE

Many studies (e.g., Liu and Wang, 2007; Li et al., 2008; Chen et al., 2013; Li et al., 2013a; Wang et al., 2015a) have discussed a wide range of natural and anthropogenic factors that may contribute to grassland degradation in the QTP region. These factors can be categorized as (Harris, 2010): 1) a harsh environment and fragile soils; 2) climate change, including declining precipitation, warming, receding glaciers, and permafrost reductions; 3) small mammal populations; 4) rangeland conversion to arable lands; 5) obsolete livestock husbandry methods; 6) privatization and sedentarization; and 7) overgrazing, including overstocking arising from increases in livestock, overstocking arising from an increase in the population of pastoralists, and overstocking arising from socioeconomic incentives.

However, due to the lack of ecological and socioeconomic baseline information for such a vast area, long-term monitoring projects, and studies on driver interactions and feedback processes (Fassnacht et al., 2015), the causes of the documented degradation processes have remained contentious in the field of grassland ecology and environmental policy (Harris, 2010; Harris et al., 2015; Wang et al., 2015b). In this paper, these causative factors will be reevaluated. The exception will be the conversion of grassland to farmland, an alteration in land use that the government has recently prohibited across the entire QTP (Chen et al., 2015). The discussion of factors contributing to grassland degradation on the QTP will follow the point-by-point order of Harris (Harris, 2010), based on empirical studies.

Grassland Degradation on the QTP Due to Harsh Environments and Fragile Soils

Harris (2010) held the view that there was insufficient evidence that grassland degradation on the QTP was due to a harsh environment and fragile soils. However, Chinese researchers have generally included the occurrence of natural disasters, such as snowstorms and other adverse conditions, in their definition of a "harsh environment" (Fu et al., 2012; Li et al., 2013c; Wu et al., 2014; Wang et al., 2016c; Li et al., 2018b). In this context, harsh environmental conditions could indicate a high fragility of grasslands to environmental disturbances, their high sensitivity to climate change triggers in the Asian monsoon region, pronounced feedbacks on climate change and human activities, or difficult recovery when the grasslands are degraded (Wang et al., 2013; Li et al., 2013a; Ren et al., 2013b; Chersich et al., 2015; Wang et al., 2015a; Zhang et al., 2016; Wang et al., 2016a). A harsh environment could also be construed to mean that the climate's frigidity limits plant growth to a short period of 90–120 days, resulting in a diminished forage yield (Dong et al., 2013). To meet economic needs under such conditions, herders likely would increase livestock populations to compensate for the low efficiency of meat production, leading, in turn, to overgrazing (Feng et al., 2013).

Harsh environments also impact the partitioning of plant biomass between roots and shoots. Given that available subsurface resources must be captured efficiently at the specific depths and times they are available, relatively large root biomass is necessary. This, however, requires high carbon maintenance costs, which must be covered by comparatively small quantities of photosynthetically active aboveground plant parts (Schleuss et al., 2015). This paper's authors currently agree with Huang et al. (2017) that inherently harsh environment conditions partially regulate QTP ecosystem degradation.

Grassland Degradation on the QTP Due to Climate Change

Climate change is seen to affect the QTP through a combined reduction in precipitation and increase in temperature, which results in soil desiccation, receding glaciers, and reduced permafrost depth (Kääb et al., 2007; Mu et al., 2017). Significant warming of the QTP's soils (0.458°C decade^{-1} on average) between 1980 and 2014 was associated with a small but insignificant rise in precipitation. Whereas most studies have focused solely on the effect of warming on grassland degradation (Table 2), few have considered the combined effect of warming and slightly increased precipitation. In these latter studies, the relationship between precipitation and temperature was complex (Luo et al., 2016) and results were inconsistent. Some studies (Piao et al., 2012; Liu et al., 2013; Wang et al., 2013; Chen et al., 2014; Zhang et al., 2014; Piao et al., 2015; Lehnert et al., 2016; Xu et al., 2018) found that recent years' warm-wet climate was associated with an increase in grassland productivity across the QTP region, but Wang et al. (2016a) found it to have little effect on vegetation growth in alpine grasslands. Zhang et al. (2016) found that enhanced rainfall, rather than warming, significantly reduced soil microbial diversity by changing soil nutrients and moisture levels in alpine grassland ecosystems.

A reduction in permafrost also had complex effects on grassland degradation (Table 3). The response of permafrost to a warming climate included rising ground temperatures, a deepening active layer, and a shrinkage of the total area of permanently frozen ground (Jin et al., 2011). Peng et al. (2015) also investigated the effect of the construction of engineered structures on permafrost and concluded that such disturbances could lead to greater permafrost degradation in warm (vs. cold) permafrost regions.

At present, despite these contradictory observations, and the fact that most investigators drew on others' work rather than undertaking empirical research through remote sensing or field experiments, climate change is still considered a driver of grassland degradation on the QTP (**Appendix 2**).

Table 2
Warming effect on grassland degradation and reasons on the Qinghai-Tibetan Plateau.

Studies	Warming effect
	Negative effect
Klein et al., 2004, 2007;	Reduced species richness and decreased rangeland quality
Li et al., 2011	Caused grassland damage through trophic interactions
Liu et al., 2012	Reduced plant reproductive output due to their physiological response
Wu et al., 2013	Caused grassland damage through variation in dust storm patterns
Song et al., 2018	Reduced plant aboveground biomass due to soil drying
	Positive effect
Wang et al., 2016a	Increased NPP due to warming being beneficial to grassland growth
	Complicated effect
Xue et al., 2014; Zhang et al., 2015	Reduced live vegetation of cultivated grassland and alpine steppe but increased the live vegetation of alpine meadow through changes in soil water content and its gradients

Table 3
Effects of declining permafrost on the Qinghai-Tibetan Plateau on grassland degradation.

Studies	Effect of reducing permafrost
	Negative effect
Jin et al., 2011; Wang et al., 2011; Yang et al., 2011; Wang et al., 2012; Ye et al., 2013; Wang et al., 2015b; Fassnacht et al., 2015; Liu et al., 2015b; Wang et al., 2016b; Mu et al., 2017; Wu et al., 2018	Caused grassland degradation as vegetation cover was significantly related to areas of permafrost Resulted in lowered levels of ground water or downward drainage of water to deeper aquifers, leading to an extremely dry topsoil, which is not conducive to grassland growth Reduced microbial activity in the newly thawed permafrost Increased risk of wind or rain erosion at high altitudes Accelerated decomposition of soil organic matter
	Weak effect
Yi et al., 2014; Feng et al., 2016; Wu et al., 2016	Weak correlations between: release of carbon and disappearing waterproofing function of permafrost, and grassland degradation (vegetative cover) and permafrost degradation In the QTP's arid area, permafrost has little effect on soil organic carbon
	Positive effect
Shen et al., 2014; Cuo et al., 2015; Zhou et al., 2015	Mitigated low-temperature stress Promoted an active nutrient cycle Lengthened the growing season

Grassland Degradation on the QTP Due to Small Mammals

Several studies suggest that grassland degradation on the QTP can also be caused by overpopulation of small mammals, such as zoko *(Eospalax fontanierii)* and pikas *(Ochotona curzoniae)* (Li et al., 2012; Lu et al., 2012; Li et al., 2013c; Zeng et al., 2013; Qu et al., 2015). Several research groups have presented arguments both

Table 4
Effect of small mammals on grassland degradation on the Qinghai-Tibetan Plateau and reasons.

Studies	Effect of small mammals
	Negative effect
Dong et al., 2013; Li et al., 2011; Peng et al., 2015; Harris et al., 2015; Su et al., 2015; Sun et al., 2015	Reduced both gross and aboveground ecosystem production as burrow density was negatively correlated with plant biomass Caused grassland degradation by burrowing through turf cover and gnawing at herbs Reduced rangeland value to pastoralists through clipping and burrowing activities Worsened grassland degradation as zokor-suitable habitats increase under warm-wet conditions
	Positive effect
Harris et al., 2014; Sun et al., 2015; Smith et al., 2018	Reduced extinction risk of Tibetan fox as pikas are prey of the Tibetan fox Enhanced native biodiversity and provided other important ecosystem functions because some obligate predators of pikas and endemic birds nesting in pika burrows coexist

for and against the involvement of small mammals—even at uncontrolled densities—in grassland degradation (Table 4). Harris et al. (2015) found that under uncontrolled densities, pikas appeared in some cases to promote the production of forbs, such as *Potentilla,* while limiting the production of their preferred forage, sedge. In other cases, similar densities of pikas appeared to restrict production of *Stipa* or promote it. Therefore, as the threshold density at which pikas are to be controlled remains undetermined, rodenticide, which has negative environmental effects, and poses a risk to nontarget species and hydrological function (Wilson and Smith, 2015; Badingquiying et al., 2016), should be employed with caution.

Grassland Degradation on the QTP Due to "Traditional Pastoral" Management

Historically, through collective nomadism, the people living on the QTP have played a crucial role in the formation and maintenance of the QTP's vast grassland environments (Foggin, 2012; Cao et al., 2018a). Traditionally, warm-season grazing is compatible with conserving species diversity and sequestering nutrients in topsoil, while cold-season grazing is suitable for sequestering nutrients in deeper soil strata; accordingly, periodic cold- and warm-season grazing would constitute a suitable and sustainable grazing regime to maintain alpine meadows (Wu et al., 2017b). Others (e.g., Whitford and Steinberger, 2012; Wang et al., 2016a; Li et al., 2017) also see migratory grazing as having the advantage of using the heterogeneous and vast geographic space to adapt to the highly variable resources and rich vegetative biomass. These researchers view changes in the lifestyles of herdsmen as one of the main factors causing peatland loss on the QTP (Yang et al., 2017).

The prejudice against mobile populations held by the numerically dominant sedentary agriculturalists, however, has led pastoralists to be accused of exploiting and misusing natural resources (Cao et al., 2017). Thus, "traditional pastoral" practices have been erroneously regarded as a cause of degradation by most Chinese researchers (Harris, 2010; Yeh et al., 2017), although a small proportion of Chinese researchers believe that these practices are consistent with long-term sustainability (Cao and Wang, 1995; Yan et al., 2005; Zhang and Li, 2008; Ren et al., 2010). In recent years, a growing number of Chinese scientists (e.g., Cao et al., 2011; Fu et al., 2012; Cao et al., 2013a; Chen and Zhu, 2015; Wu et al., 2015b; Cai and Li, 2016) have opted to support the view that collective grazing has distinct ecological, social, and economic advantages. These researchers have used a series of empirical studies comparing individual household management practices with collective management practices (also termed *multihousehold management practices* or *group management*). Some Chinese researchers (e.g., Wu et al., 2014), however, note that pastoral grazing systems can still damage ecosystems at altitudes exceeding 4 000 m, where natural productivity is limited and < 1.5 Mg ha^{-1} edible forage is available. The shortage of forage, especially outside the growing season, restricts the development of livestock farming. The discrepancy between the forage supply and livestock demand will inevitably lead to damage of the natural grassland ecosystems at high altitudes (He et al., 2016).

Grassland Degradation on the QTP Due to Privatization and Sedentarization

The Chinese government implemented policies in the 1990s that required the privatization of user rights to pastures in order to reduce perceived grassland degradation on the QTP (Yeh et al., 2017). Only limited functionality, however, can be expected from such a rigid and unidimensional land-use management approach, given the highly diverse geographical and social features and

Table 5
Quantitative and qualitative ecological and socioeconomic indicators for individual household management patterns (IMPs) and collective (group) management patterns (CMPs).

Indicators	CMP	IMP
Ecological		
Transhumance	Yes	No
Vegetation condition	Good	Poor
Soil nutrient status	Good	Poor
Water sources	Good	Poor
Pasture-use efficiency	High	Low
Pasture quality	High	Low
Socioeconomic		
Income	Higher	Lower
Cost	Lower	Higher
Equality	Yes	No
Livestock mortality	Lower	Higher
Milk production	No change	Decrease
Livestock limit agreement	Yes	No
Monitoring mechanism	Yes	No
Outside assistance	Yes	No
Social relations	Good	Average
Cultural heritage	Better	Worse
Risk	Low	High

More details in Fu et al. (2012), Næss (2013), Chen and Zhu (2015), Gongbuzeren and Li (2016), Yu and Farrell (2016), Wang et al. (2016c), and Cao et al. (2018b, 2018c).

climate variability in the QTP (Yu and Farrell, 2013). After grassland privatization, the scope and space of available rangeland were reduced, and traditional transhumance barely survived across the QTP (Fu et al., 2012; Wang et al., 2016a; Li et al., 2017; Yang et al., 2017). The mobility of livestock and opportunity to follow grass and water, which characterized the herders' past life, was destroyed by the allocation of set pieces of land to individual households (Hua and Squires, 2015). Li et al. (2017) found that pasture privatization from 1984 to 1994 created a land-use regime shift that decreased pastoral mobility and that the installation of iron fences as private pasture borders from 2004 to 2007 marked the onset of degradation on the eastern QTP.

To explore the linkages between grassland privatization and grassland degradation, several other researchers have compared the ecological and sociometric benefits between individual household management patterns (IMP) and collective (group) management patterns (CMP) as described earlier. These empirical studies and the ecological and sociometric distinctions between IMP and CMP are presented in Table 5. In inner Mongolia, fences were removed by cooperating householders to pool pastoralists' resources on their allocated land and to allow the practice of a modified rotational grazing system (Hua and Squires, 2015). This property regime, which reintroduces some nomadic elements, has been shown to enhance long-term sustainable rangeland management in China's Gansu Province (Hua and Squires, 2015), where it increased the temporal and spatial scale of rotational stocking (Shang et al., 2014).

To improve the welfare of nomads under the current policy of privatization, the government has now launched a comprehensive program subsidizing the establishment of stockyards and permanent settlements on winter pastures (Fassnacht et al., 2015). The present livelihood adaption strategies related to sedentary grazing have provided greater convenience to the local population, safer drinking water, improved medical conditions, and economic profitability of the herding livelihood (Wang et al., 2015b; Wang et al., 2016c). However, the expected benefits from settlements have not been forthcoming, and land degradation and pastoralist poverty have not been eliminated (Yu and Farrell, 2016). For example, livestock typically remain in fenced areas near the settlements or overnight campsites, and thus grazing intensity and effects are highest near the settlements and the effect of trampling on the soil and vegetation is exacerbated (Dorji et al., 2013; Lehnert et al., 2014; Gongbuzeren et al., 2015). Furthermore, settlements have led to the conversion of native meadows into pastures (Zhang et al., 2012), while local grazing systems have raised dependence on artificial feeding and inputs coming from outside the grazing system (Wang et al., 2016c). This has led to a decline in biodiversity due to the increase in population size and growth rate (Wang et al., 2015b).

Grassland Degradation on the QTP Due to Overgrazing

Much of the literature suggests that overgrazing is caused primarily by population growth and pressures from a market-based economy (Harris, 2010; Yeh et al., 2017). Overgrazing reduces the partitioning of assimilates to belowground biomass, which, in turn, decreases the uptake of belowground resources, soil nutrients, and moisture and reduces species richness, possibly triggering grassland degradation (Schleuss et al., 2015; Zhang et al., 2015; Zhang et al., 2016; Chai et al., 2017). Overgrazing has clearly occurred in certain regions of the QTP, though not throughout. Dong et al. (2013) found that the rate of overstocking reached a level of 130%−140% in the Hainan and Huangnan Tibetan Autonomous Prefectures. Based on the grassland area size or net primary productivity (NPP) per unit grassland, Huang et al. (2016) concluded that there was overgrazing on the QTP. Others (e.g., Li et al., 2013c; Wu et al., 2015b; Wang et al., 2016c) also found that there was a positive correlation between population increase and livestock increase (**Appendix 3**).

Alternatively, an analysis by Cao et al. (Cao et al., 2013b) concluded that there was little evidence from national data to suggest that overgrazing, per se, is responsible for grassland degradation across China's pastoral grazing areas. From 2001 to 2013, herds of livestock were significantly decreased due to the livestock reduction policy on the QTP (Chen et al., 2014; Cai et al., 2015; Wang et al., 2016c). Moreover, with the advancement of industrialization and urbanization, a large proportion of herders have moved to towns and cities to take advantage of better education for their children and to improve their quality of life, often leasing their grasslands (Yeh and Gaerrang, 2011; Wu et al., 2015b; Cao et al., 2018a). As the pastoral population declines, livestock numbers may also decrease. In addition, some herders have changed their food structure by eating less meat and more rice and flour to reduce daily expenses brought on by a market-based economy (Fu et al., 2012; Wang et al., 2016c), which could, in turn, reduce livestock population. This suggests that a population increase may not be as highly correlated with overgrazing or grassland degradation in the QTP, as suggested by Harris (2010) and Cao et al. (2013a). A synthetic analysis of 61 studies carried out by Lu et al. (2017) concluded that grazing intensity could lead to greater loss of ecosystem function and, thus, ecosystem degradation. Harris et al. (2015), however, found that most plant species in this region have coevolved to tolerate and perhaps benefit from periodic grazing at relatively high intensity.

Perspectives on Mitigating Degradation in the Face of New Evidence

On the basis of new empirical evidence subsequent to Harris (2010), it is the present authors' view that climate change (see Tables 2 and 3), small mammals (see Table 4), privatization and sedentarization (see Table 5), harsh environmental conditions and fragile soils, and overgrazing are contributing to grassland degradation in the QTP. Traditional pastoral management, however, does not appear to contribute to grassland degradation in this region. Estimations of the total area of degraded grassland, however, are needed, and criteria for degradation have not yet been properly addressed (see Table 1). These two factors are fundamental to exploring the causes of grassland degradation and adopting measures for grassland management across the QTP. With capital efficiency and technical accuracy, the area of grassland degradation must be determined accurately, and degradation criteria must be set. As different grassland types manifest degradation in distinct manners, criteria for each type may be necessary.

A mischaracterization among policy makers of the underlying causes of grassland degradation in the QTP has presented obstacles to current and past grassland management practices in the region. The exclusion of livestock from certain pastures by establishing fences, for example, is a common tool for conserving and restoring native vegetation (Spooner et al., 2002; Da et al., 2012; Li et al., 2013a). However, these policies have not been success full (Chen et al., 2014). For example, the absence of grazing in remote areas has led to a decrease in carbon sequestration (Silke et al., 2012); likewise, livestock exclosures did not change seasonal patterns in CO_2, CH_4, and N_2O fluxes (Da et al., 2012) or result in reductions in annual productivity of palatable, perennial graminoids (Harris et al., 2015). Moreover, fencing has had no significant effects on heavily and extremely degraded grasslands (Li et al., 2013a), although establishing a perennial artificial grassland could be the best strategy for restoring the black-soil-type grasslands native to the QTP (Li et al., 2018a). The effects of such policies lose significance with an increase in years since restoration (Li et al., 2014). Privatization and sedentarization have negative impacts on ecosystems and society despite having positive impacts on livelihoods and animal husbandry (Gongbuzenren et al., 2015), Therefore a new management style based on individualized private ownership of properties, such as group and multihousehold management, is needed (Wang et al., 2015b). Innovative approaches should be developed to provide social services and access to modern development for pastoralists who choose to remain in pastoral areas. Such measures include the development of mobile medical facilities and schools or the application of modern telecommunication technology to enhance medical and educational needs (Gongbuzeren et al., 2015).

Overall rehabilitative measures should target the underlying causes of degradation, which may vary geographically across the region, to be effective and successful (Li et al., 2013b). Accordingly, understanding the relationship between technical efficiency and ecological performance would be helpful in balancing local economic development and environmental protection (Huang et al., 2016). Furthermore, a rigorously quantifiable definition of "degradation" is still needed, despite the term's ubiquitous application to rangelands (Hruska, 2014). In the process of defining grassland degradation, more attention should be given to soil nutrients, plant community characteristics, and ecosystem resilience rather than focusing solely on plant biomass and species richness.

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Appendix A. Supplementary data

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