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Review

Strategies to alleviate poverty and grassland degradation in Inner Mongolia: Intensification vs production efficiency of livestock systems

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ABSTRACT

Semi-nomadic pastoralism was replaced by sedentary pastoralism in Inner Mongolia during the 1960's in response to changes in land use policy and increasing human population. Large increases in numbers of livestock and pastoralist households (11- and 9-fold, respectively) during the past 60 yrs have variously degraded the majority of grasslands in Inner Mongolia (78 M ha) and jeopardize the livelihoods of 24 M human inhabitants. A prevailing strategy for alleviating poverty and grassland degradation emphasizes intensification of livestock production systems to maintain both pastoral livelihoods and large livestock numbers. We consider this strategy unsustainable because maximization of livestock revenue incurs high supplemental feed costs, marginalizes net household income, and promotes larger flock sizes to create a positive feedback loop driving grassland degradation. We offer an alternative strategy that increases both livestock production efficiency and net pastoral income by marketing high quality animal products to an increasing affluent Chinese economy while simultaneously reducing livestock impacts on grasslands. We further caution that this strategy be designed and assessed within a social-ecological framework capable of coordinating market expansion for livestock products, sustainable livestock carrying capacities, modified pastoral perceptions of success, and incentives for ecosystem services to interrupt the positive feedback loop that exists between subsistence pastoralism and grassland degradation in Inner Mongolia.

1. Introduction

Grasslands occupy 78 M ha (67%) in the Inner Mongolia Autonomous Region (IMAR) in the People's Republic of China. This extensive grassland provides multiple ecosystem services for 24 M human inhabitants, 60% of whom live in rural areas and derive their livelihoods primarily as pastoralists (Li et al., 2007b) (Fig 1). Current livestock production systems are unsustainable as 55–80% of total grassland area is categorized in varying stages of degradation, plant production has declined 30–70%, and degradation claims an additional 2% of the grassland area each year (Tong et al., 2004; Brown et al., 2008 p. 42; Xue and Zhang, 2009). Specific aspects of grassland degradation include modified plant species composition (Ho, 2001), declining biodiversity (Bai et al., 2007), and accelerated soil erosion (Shi et al., 2004). The environmental consequence of these land use patterns are evidenced by desert expansion, regional and continental dust storms, and environmentally induced human migration in extreme cases (Shi et al., 2004; Liu and Diamond, 2005).

The occurrence of grassland degradation closely parallels rapid increases in numbers of livestock and pastoralist households that intensifies grassland exploitation by reducing land area per household and restricting livestock mobility (Tong et al., 2004; Yu et al., 2004). The number of sheep units (SU; forage demand of a

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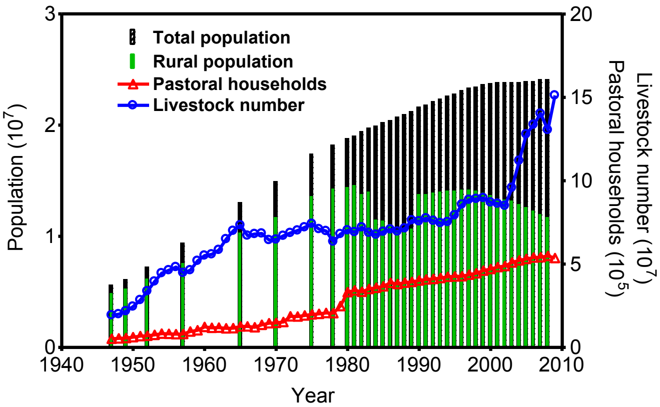

Fig. 1. Trends in rural and total human populations, pastoralist households, and livestock numbers in IMAR 1947–2009.

50 kg ewe with lamb; 2 kg day^{-1}; allows aggregation of demand by various livestock species) increased 18-fold from 8.4 M in 1947 to 152 M in 2009, pastoralist households increased 9-fold from 52,000 to 510,000, and total human population increased 4.4 fold from 5.5 M to 24 M over this period (Fig. 1). Current livestock numbers, supported by supplemental feeding during the winter, have been estimated to exceed the ecological carrying capacity of these grasslands by 70–100% (Brown et al., 2008 p. 47), but evidence-based assessments of sustainable livestock carrying capacities are lacking (Harris, 2010) as are cause-effect mechanisms of degradation (Tong et al., 2004). Rapid increases in livestock numbers are a direct consequence of major policy modifications. The first occurred with collectivization in the 1950's and 60's when the Government encouraged development of large-scale communes patterned on Russian agricultural models and the second conveyed land and animal-use rights to individual households during the 1990's (Jiang, 2005; Li et al., 2007b).

Conversely, policy implementation to confront grassland degradation by reducing livestock numbers is widely perceived as being incompatible with livelihoods of 14.4 M pastoralists in IMAR (Yu et al., 2004; Li et al., 2007b; Harris, 2010). Government officials and some academics respond to this solution by indicating that 'we must feed the people' (Dong et al., 2012)—a perception likely founded upon agrarian land-use values that are expressed as ecological construction. The central theme of ecological construction is improvement of the rural environment through implementation of intensive land use practices that are often implemented without regard for ecological constraints (Jiang, 2006). Consequently, degradation continues despite the imposition of grazing bans and restoration projects because little attention has been given to the reduction of livestock numbers (Liu, 2010; Michalk et al., 2011). The perceived tradeoff between grassland sustainability and pastoral livelihoods has stifled development and adoption of more aggressive and comprehensive strategies to confront grassland degradation and likely underlies support for the prevailing strategy of intensified livestock production systems. We introduce an alternative and potentially more sustainable strategy that emphasizes a rapid transition from subsistence pastoralism to market-based livestock production systems -supported by the rapidly growing Chinese economy - to resolve this perceived tradeoff between grassland sustainability and pastoral livelihoods. It is essential that this strategy be evaluated within the context of social-ecological systems because biophysical processes, socioeconomic conditions of pastoralists, and land-use policy represent major components of this challenge in IMAR (Taylor, 2006; Brown et al., 2008 p. 266).

2. Drivers and measures of degradation

Statistics maintained by the Chinese Agricultural Ministry are indicative of current grassland over-exploitation in IMAR. The number of SUs is currently estimated at 140 M while the livestock carrying capacity is estimated to be 44 and 31 M SU's in a normal rainfall and drought (30% below long-term mean) year, respectively. This stocking rate exceeds the estimated carrying capacity by 3.2 and 4.5 times, respectively. We have estimated that approximately 95 MT of dry aboveground plant mass are produced per year in IMAR assuming a mean productivity of 1200 kg ha^{-1} over the entire 78.8 M ha region. This assumption seems reasonable for IMAR considering the very large variability in grassland production that exists in it (Ni, 2004). Two kg of dry plant mass day^{-1} are required to support a SU, which translates to 730 kg SU yr^{-1} and 202 MT yr^{-1} for all 140 M SUs. Assuming that livestock harvest approximately 50% of the total aboveground plant mass—an optimistic harvest efficiency with the remainder lost to weathering, senescence and insects—grasslands provide only 24% of the plant mass required to maintain livestock body weight on an annual basis. The potential to realize net livestock production from this plant mass is further reduced by energy requirements associated with low temperature stress, animals foraging large distances, and nutritional requirements for gestation and lactation. This assessment of grassland over-exploitation is corroborated by large losses in animal live weight (up to 30%) during the winter and reliance upon supplemental fed for livestock survival (Kemp et al., 2011).

Policy governing land tenure was modified from a collective-state property regime (1955–1979) to the Household Production Responsibility System (HPRS) by the central government during the economic reform period in the 1980's (Li et al., 2007a). HPRS confers pastoralists an inheritable right of use of both land and livestock for 30–50 years with the intent of increasing agricultural production. Land remains property of the state and cannot be sold or used as an asset for acquiring loans, but it is permissible to rent land to other pastoralists, primarily on an annual basis, which precludes appropriate incentives and often encourages grassland exploitation. This policy has generated considerable debate because household land areas may be of insufficient size (1000–10,000 mu; 67–670 ha) to sustainably maintain pastoral incomes (2989 RMB per capita; Brown et al., 2008 p. 21) above the poverty line ($US 2 person^{-1} day^{-1}). Households with larger land areas often have lower mean stocking rates, greater flexibility in grazing management and increased opportunities to produce supplemental feed to maintain animals during the winter. The relative contribution of HPRS to grassland degradation is poorly documented and remains controversial (Li et al., 2007a; Harris, 2010), but recent events do suggest that exclusive land tenure and sedentarization may exact significant costs to human and natural systems in semiarid grasslands (Taylor, 2006; Hobbs et al., 2008).

3. Materials and methods

3.1. Study area

Grasslands of IMAR exhibit an extreme continental climate with 95% of the mean annual precipitation occurring within the five summer months and 75% during June, July and August. Temperatures are characteristic of continental climates with mild summers, but may fall to −40 °C in cold, dry winters to produce considerable livestock mortality (Zhang, 1990). These extreme winters are often followed by summer drought, as the first two months of summer (May–June) have the greatest rainfall variability. These conditions result in a short growing season that extends from June through September, but livestock typically graze throughout the year.

Desert steppe is located in the western portion of the Inner Mongolian grassland and it is dominated by several short statured perennial grass species in the genus *Stipa* spp. (Sai, 1995). This plant community often includes low growing shrubs such as *Caragana* spp. and *Kochia* spp.. The mean annual precipitation ranges from 150 to 250 mm and mean annual air temperature is 2–5 °C. The soil is a brown chestnut with low fertility. Baseline data was collected from this grassland to develop the economic model for livestock production in relation to stocking rate.

3.2. Data acquisition

All human and livestock demographic data in Figs. 1 and 2 were derived from the Inner Mongolia Statistical Yearbook maintained by the Chinese Ministry of Statistics and Household survey (Committee of Inner Mongolia Statistics, 2010). A participatory approach using pastoralist interviews was used in different grassland regions. Within each region, data were collected at three typical villages.

3.3. Economic modeling

Modeling of livestock production was conducted with linear programming for a typical household (Kemp and Michalk, 2010) based on biophysical and financial data derived from surveys of a small subset of households in the region, supplemented with relationships derived from nearby grazing experiments. Models assumed a mean precipitation year during which animals would be fed to maintenance and periodically housed in a warm shed during the winter to minimize weight loss.

4. Results

4.1. Strategies to confront grassland degradation

The most prevalent strategy to confront grassland degradation emphasizes technological approaches to intensify production systems as a means to support high livestock numbers (Jiang, 2006; Li et al., 2007a). We propose an alternative strategy that advocates increased bio-economic efficiencies to increase pastoral incomes with fewer livestock and less adverse impacts on grasslands. Neither strategy assumes that it is possible to reinstate semi-nomadic pastoralism in IMAR, which was eliminated during collectivization in the 1950's and 60's, given the current density of people, pastoral households, and livestock, coupled with land tenure policy (HPRS) that has assigned land to specific households (Jiang, 2005; Li et al., 2007a).

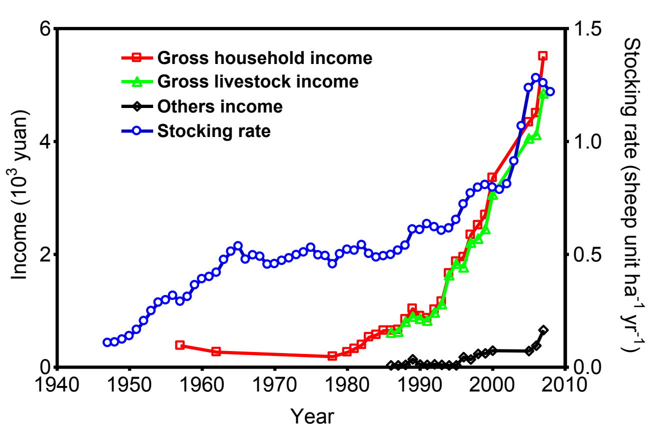

Fig. 2. Trends in stocking rate (SU) and gross household income derived from livestock and other revenue source in IMAR 1955–2009.

4.2. Intensification of livestock production systems

Technological solutions supported by infrastructure and energy inputs to promote production stability and income for existing livestock production systems have received considerable attention throughout China (Xu, 1998; Brown et al., 2011; Dong et al., 2012). Intensive grazing systems, agronomic forage production, and greater supplemental livestock feeding have been specifically proposed for IMAR (Jiang, 2006; Li et al., 2007a). Rotational grazing is implemented by fencing grassland into multiple units (commonly 4–16) that are successively grazed by one flock or herd to produce alternating intervals of grazing and plant rest from defoliation and to improve uniformity of livestock distribution and biomass utilization (Briske et al., 2008). These grazing systems emphasize local rotation of livestock and are not intended to replace previous seasonal livestock migration routes over large regions to track varying patterns of rainfall and plant production.

A majority (84–92%) of experimental comparisons ($n = 47$), primarily from the US and South Africa, show no ecological benefit to plant and animal production in rotational grazing systems compared to continuous grazing on native grasslands (Briske et al., 2008). Grazing experiments in IMAR confirm these conclusions (Wang et al., 2009) and further establish that precipitation and grassland productivity relative to the forage requirements of livestock are the main drivers of plant and animal production (Bai et al., 2007; Briske et al., 2008). This indicates that costly investments in fencing and water development to implement rotational grazing systems appear unjustified in IMAR, especially given that livestock distribution and biomass harvest are currently maximized.

We further challenge use of intensified forage and crop production for supplemental livestock feed as a means to decrease pastoral dependence on grassland production (i.e., nurturing land for land) on the basis of three major arguments (Jiang, 2006; Li et al., 2007a). First, it will likely promote retention of livestock numbers that greatly exceed the ecological carrying capacity and create conditions for further grassland degradation (Yu et al., 2004; Brown et al., 2011). Second, it assumes that pastoralists can be dissuaded from retaining large numbers of animals when supplemental feed is available or grassland biomass remains at the end of the growing season. Third, indirect costs of intensified forage production (e.g., planting, irrigation, and fertilization) further reduce ecological production efficiency in a similar manner to those identified for biofuels (Tilman et al., 2009). Incentives to increase crop and forage production on arable lands will directly compete with low cost food production required to support a large human population, promote grassland conversion to cropland, and intensify grazing on remaining grassland (Liu and Diamond, 2005; Ye and van Ranst, 2009). Policy enacted to encouraged grain production resulted in the conversion of 20.7 M ha of grassland to cropland in IMAR between 1966-1976; land conversion continued until 1985 when the Grassland Law made grassland conversion illegal (Jiang, 2005).

Supplemental livestock feeding is a common and necessary practice in IMAR that enables animals to survive long, severe winters and reoccurring summer drought. The continental climate of IMAR supports a short growing season that extends from June through September (120 frost-free days), the majority of annual rainfall occurs during the summer, and extreme winter temperatures (−40 °C) frequently contribute to livestock mortality (Kemp et al., 2011, 2013). However, excessive animal numbers that graze grasslands throughout the year have exacerbated this dependence on supplemental feeding to the extent that it has become a major contributor to grassland degradation.

4.3. Enhanced efficiency of livestock production systems

Pastoralism in IMAR, as in other pastoral societies, emphasizes maintenance of large numbers of animals to accumulate wealth and buffer future risk, rather than animal production efficiency or net profitability (i.e., keeper model) (Ellis and Swift, 1988; Allsopp et al., 2007; Harris, 2010). As many as 50% of the animals retained by pastoralists in IMAR, do not contribute to reproductive success because of their age and poor physical condition (Kemp et al., 2011). Emphasis on income maximization from livestock production with minimal consideration for net economic return appears to be the main driver for this traditional practice as shown by proportional increases in total gross livestock revenue and household income with increasing stocking rate (Jiang, 2006) (Fig. 2). High gross livestock incomes are maintained by supplemental feeding, especially during the winter. However, maximization of livestock income simultaneously minimizes net household income because supplemental feed costs, in the form of hay, crop residues, or commercial feed, greatly increase livestock production costs when carried out for 5–6 months per year.

Economic models developed for desert steppe grasslands indicate that optimum net financial returns occur at a stocking rate of 0.5 ewes ha^{-1} as opposed to the traditional stocking rate of 2.0 ewes ha^{-1} (Fig. 3). Net household income can be optimized by substantially reducing stocking rates and feeding a smaller number of more productive animals from December to April to maintain live weights and enhance animal production in the subsequent growing season (Kemp et al., 2011). Maximization of livestock revenue in households restricted to small land areas incurs high supplemental feed costs, marginalizes net household income, and promotes retention of larger numbers of animals to create a positive feedback loop that escalates grassland degradation. A strategy advocating increased livestock production efficiency may interrupt this feedback loop by increasing net pastoral incomes with fewer animals and less damage to grasslands (producer model).

The recommended removal of at least 70% of the current SUs (76–106 M) from IMAR (Brown et al., 2008 p. 47) is proportionally similar to the anticipated difference between ecological and economic carrying capacities associated with nomadic pastoralism and commercial livestock ranching, respectively (Behnke et al., 1993). While data to support this contention is limited, Kemp et al. (2013)

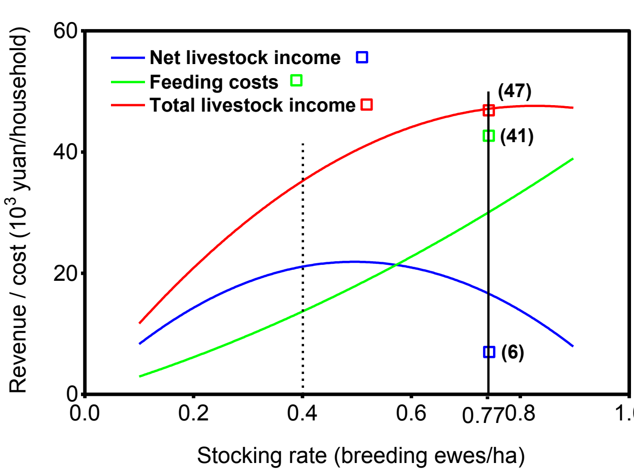

Fig. 3. Model simulations for gross and net livestock income and supplemental feed costs relative to livestock stocking rates (ewes ha^{-1}) for pastoralist households near Xilingol in IMAR. The vertical dashed and solid lines depict these variables with improved production efficiency (data from Han et al., 2011) and current conditions derived from pastoralist interviews, respectively.

found that a 50% reduction in livestock numbers on the Desert Steppe to 0.8 sheep-units (SU, adjusted to a 50 kg sheep) ha^{-1} for the summer period resulted in a 50% increase in net income. Wang et al. (2011) concluded that the optimal utilization on the Desert Steppe in summer, which would protect the grassland and ensure stable sheep production, was about 30%. This could be achieved with a stocking rate that is equivalent to that reported by Kemp et al. (2013) and is at the lower range of stocking rate proposed by Zhixin and Shuyou (1989) for winter grazing when the grassland could tolerate greater grazing pressure. The lower stocking rates increase grassland production per animal, which is consistent with both the 'producer' model of livestock management and grassland sustainability, but it is inconsistent with the 'keeper' model of pastoralists that emphasizes large flock size in the prevailing socioeconomic conditions in IMAR (e.g., Behnke et al., 1993; Allsopp et al., 2007).

Programs to promote a shift from the 'keeper' to the 'producer' livestock management model will require development of markets that will pay premiums for quality in addition to quantity of animal products to provide incentives to optimize productivity per animal, rather than to maximize animal numbers per unit area. The 'producer' model also provides opportunities for diversification of livestock products in the form of organic and specialty meat, wool, cashmere, and dairy products, which could yield substantial value added to further incentivize lower stocking rates and grassland sustainability. As a result of the study by Kemp et al. (2013), the local government of the Siziwang Banner implemented a program of livestock reduction with the objective of improving household income. We expect that adoption of this model will evolve as other governments promote livestock reduction and herders become aware of its economic benefits.

5. Discussion

The potential success of market-based livestock production to alleviate poverty and degradation is dependent upon the simultaneous development of four interrelated actions within these social-ecological systems. First, livestock markets, primarily in the affluent eastern and southern Chinese cities, and transportation infrastructure linking IMAR with these markets requires greater development. Market globalization has increased per capita GDP of China approximately 10-fold in the past two decades and this has been associated with a two- and three-fold increase in per capita meat consumption in eastern cities and rural areas, respectively (Liu and Diamond, 2005). Greater wealth and livestock demand have increased meat prices corroborating our assertion of emerging livestock markets to support market-based livestock production (Brown et al., 2008, p. 199). However, the small, fragmented markets that currently exist often provides marginal value for livestock products and high transportation costs and limited transportation infrastructure seriously constrain market expansion as evidenced by 5-fold greater mutton and beef consumption in northern than in southern cities. The capacity for fair livestock market structures, cost effective transport, improved meat processing and storage, and food safety precautions are essential for continued expansion of domestic and international livestock markets (Brown et al., 2008, p. 202; Hobbs et al., 2008). An initial step that has been taken to improve markets for high quality livestock products in China is the development of pastoral livestock associations supported by funding from local government. A central goal is to improve the supply and demand of livestock products with private buyers to increase income derived from livestock products.

Second, is the ability and willingness of pastoralists to modify their 'keeper model' as the primary metric of successful pastoralism (Li et al., 2007b; Michalk et al., 2011). The difficulty of changing pastoral perceptions of management success has been shown by the inability of policy alone to promote voluntary reductions in livestock numbers in Africa, despite numerous attempts (Behnke et al., 1993). Cases in which reductions in livestock numbers have occurred often required high enforcement costs and evidence from a case study in Gansu Province (Ho, 2001), as well as local experience, suggests that a comparable situation may exist in IMAR. Pastoral adoption of management practices consistent with a market-based economy will require effective extension and outreach programs and the development of government-assisted demonstration farms. The availability of insurance benefits to offset the security currently associated with large flock sizes and to minimize risks associated with drought and severe winters would greatly facilitate this transition. Weather insurance, in the form of weather derivatives, may be both feasible and acceptable in China (Turvey and Kong, 2010).

Third, is greater recognition and implementation of sustainable livestock carrying capacities (Yu et al., 2004; Tong et al., 2004; but see Behnke et al., 1993). Regulations currently exist within local banners to establish livestock carrying capacities, but they often emphasize survival limits of maximum animal numbers (i.e., ecological carrying capacities), rather than numbers that balance animal production with grassland sustainability for optimal net income (i.e., economic carrying capacity). Unfortunately, even these limits on maximum numbers of livestock are often unenforced suggesting that some officials remain unconvinced of the value of livestock carrying capacities to local economies or grassland sustainability (Jiang, 2006; Waldron et al., 2011). Implementation of sustainable livestock carrying capacities will require the development of forage inventories, at both local and regional scales, to balance forage supply with animal demand and to develop contingency programs for below normal rainfall years by establishing greater forage reserves (i.e., winter pastures) that can serve as grassland restoration programs during normal and high rainfall years.

Fourth, a desperate need exists for grassland policy and incentives to support the provisioning of ecosystem services for the entire autonomous region and Nation in addition to resident pastoralists. Unfortunately, the multiple ecosystem services derived from these grasslands (e.g., soil stabilization, clean air and water, biodiversity conservation, and carbon sequestration) are underappreciated and not valued in the market economy (Dong et al., 2012), even though similar services have received greater recognition in vital forest ecosystems in China (Ouyang et al., 1999). Government incentives to maintain and promote continued provisioning of these vital services from grasslands managed by pastoralists represents an investment in environmental quality and national security. Continued grassland degradation, even at current rates, will perpetuate soil erosion, dust storms, desertification and human poverty. Programs designed to alleviate the consequence of grassland degradation after they have occurred will be more costly and have a lower probability of success compared to measures implemented to minimize their occurrence (Jiang et al., 2006; Lu et al., 2011).

6. Conclusions

We advocate adoption of market-based livestock production as a sustainable alternative to the current strategy promoting intensification of sedentary pastoralism in IMAR. This alternative strategy is not intended to replace extant semi-nomadic pastoral systems that have proven sustainable in arid and semi-arid regions (Ellis and Swift, 1988; Behnke et al., 1993), but it may have application throughout western China and other pastoral regions impacted by land subdivision and sedentarization (Hobbs et al., 2008). We acknowledge that this proposed strategy may be unique to China because escalating grassland degradation in the west is associated with increasing affluence in eastern China—a condition that does not exist in many pastoral regions.

The complex and comprehensive nature of this regional strategy requires effective integration of the socioeconomic needs of pastoralists with environmental policies to promote sustainable social-ecological systems in IMAR (Jiang et al., 2006; Taylor, 2006; Waldron et al., 2011). Attempts to independently implement components of this strategy will likely yield minimal success because of high interdependence and mutual reinforcement among them. For example, implementation of technological solutions that maintain livestock numbers, in the absence of the appropriate institutional policies and pastoral incentives, has the potential to exacerbate both poverty and degradation (Brown et al., 2008 p. 119). Similarly, policies solely targeting livestock removal run the risk of further decreasing pastoralist incomes without simultaneous efforts to promote livestock production efficiency and fair livestock market structures (Allsopp et al., 2007). It is critical that policies, incentives, and demonstrations of cost-effective livestock production be implemented simultaneously to effectively transition from subsistence pastoralism toward market-based production systems. A comprehensive framework that involves policy makers, biophysical and social scientists, and pastoral leaders is required to interrupt the positive feedback loop that currently exist between subsistence pastoralism and grassland degradation in IMAR.

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References

Allsopp, N., Laurent, C., Debeaudoin, L.M.C., Samuels, M.I., 2007. Environmental perceptions and practices of livestock keepers on the namaqualand commons challenge conventional rangeland management. J. Arid Environ. 70, 740–754.
Bai, Y., Wu, J., Pan, Q., Huang, J., Wang, Q., Li, F., Buyantuyev, A., Han, X., 2007. Positive linear relationship between productivity and diversity: evidence from the Eurasian Steppe. J. Appl. Ecol. 44, 1023–1034.
Behnke, R.H., Scoones, I., Kerven, C., 1993. Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in Africa Savannas. Overseas Development Institute, London.
Briske, D.D., Derner, J.D., Brown, J.R., Fuhlendorf, S.D., Teague, W.R., Havstad, K.M., Gillen, R.L., Ash, A.J., Willms, W.D., 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangel. Ecol. Manag. 61, 3–17.
Brown, C.G., Waldron, S.A., Longworth, J.W., 2008. Sustainable Development in Western China, China: Managing People, Livestock and Grasslands in Pastoral Areas. Edward Elgar, Northampton MA, USA.
Brown, C., Waldron, S., Zhao, Y., 2011. Policy settings to combat grassland degradation and promote sustainable development in western China. In: Kemp, D.R., Michalk, D.L. (Eds.), Development of Sustainable Livestock Systems on Grasslands in North-western China. ACIAR Proceedings No. 134, Canberra, Australia.
Committee of Inner Mongolia Statistics, 2010. Inner Mongolia Statistics. Inner Mongolia Publishing House, Hohhot.

Dong, X., Yang, W., Ulgiati, S., Yan, M., Zhang, X., 2012. The impact of human activities on natural capital and ecosystem services of natural pastures in North Xinjiang, China. Ecol. Model. 225, 28–39.
Ellis, J.E., Swift, D.M., 1988. Stability of African pastoral ecosystems: alternate paradigms and implications for development. J. Range Manag. 41, 450–459.
Han, G., Li, N., Zhao, M., Zhang, M., Wang, Z., Li, Z., Bai, W., Jones, R., Kemp, D., Takahashi, T., Michalk, D., 2011. Changing livestock numbers and farm management to improve the livelihood of farmers and rehabilitate grasslands in desert steppe: a case study in Siziwang Banner, Inner Mongolia Autonomous Region. In: Kemp, D.R., Michalk, D.L. (Eds.), Development of Sustainable Livestock Systems on Grasslands in North-western China. ACIAR Proceedings No. 134, Canberra, Australia.
Harris, R.B., 2010. Rangeland degradation on the Qinghai-Tibetan plateau: a review of the evidence of its magnitude and causes. J. Arid Environ. 74, 1–12.
Ho, P., 2001. Rangeland degradation in North China revisited? a preliminary statistical analysis to validate non-equilibrium range ecology. J. Dev. Stud. 37, 99–133.
Hobbs, N.T., Galvin, K.A., Stokes, C.J., Lackett, J.M., Ash, A.J., Boone, R.B., Reid, R.S., Thornton, P.K., 2008. Fragmentation of rangelands: implications for humans, animals and landscapes. Glob. Environ. Change 18, 776–785.
Jiang, H., 2005. Grassland management and views of nature in China since 1949: regional policies and local change in Uxin Ju, Inner Mongolia. Geoforum 36, 641–653.
Jiang, H., 2006. Decentralization, ecological construction, and the environment in post-reform China: case study from Uxin banner, Inner Mongolia. World Dev. 34, 1907–1921.
Jiang, G., Han, X., Wu, J., 2006. Restoration and management of the Inner Mongolia Grassland require a sustainable strategy. Ambio 35, 269–270.
Kemp, D., Brown, C., Han, G., Michalk, D., Nan, Z., Wu, J., Xu, Z., 2011. Chinese grasslands: problems, dilemmas and finding solutions. In: Kemp, D.R., Michalk, D.L. (Eds.), Development of Sustainable Livestock Systems on Grasslands in North-western China. ACIAR Proceedings No. 134, Canberra, Australia.
Kemp, D., Han, G., Hou, X., Michalk, D., Hou, F., Wu, J., Zhang, Y., 2013. Innovative grassland management systems for environmental and livelihood benefits. Proc. Natl. Acad. Sci. 110, 8369–8374.
Li, G., Jiang, G., Li, Y., Liu, M., Peng, Y., Li, L., Han, X., 2007a. A new approach to the fight against desertification in Inner Mongolia. Environ. Conserv. 34, 95–97.
Li, W., Ali, S., Zhang, Q., 2007b. Property rights and grassland degradation: a study of the Xilingol Pasture, Inner Mongolia, China. J. Environ. Manag. 85, 461–470.
Liu, J., 2010. China's road to sustainability. Science 328, 50.
Liu, J., Diamond, J., 2005. China's environment in a globalizing world. Nature 435, 1179–1186.
Lu, Y., Fu, B., Wei, W., Yu, X., Sun, R., 2011. Major ecosystems in China: dynamics and challenges for sustainable management. Environ. Manag. 48, 13–27.
Michalk, D., Kemp, D., Han, G., Hua, L., Nan, Z., Taro, T., Wu, J., Xu, Z., 2011. Redesigning livestock strategies to reduce stocking rates and improve incomes on western China's grasslands. In: Kemp, D.R., Michalk, D.L. (Eds.), Development of Sustainable Livestock Systems on Grasslands in North-western China. ACIAR Proceedings No. 134, Canberra, Australia.
Ni, J., 2004. Estimating net primary productivity of grasslands from field biomass measurements in temperate northern China. Plant Ecol. 174, 217–234.
Ouyang, Z., Wang, X., Miao, H., 1999. A primary study on Chinese terrestrial ecosystem services and their ecological economic values. Acta Ecol. Sin. 19, 607–613 [Chinese English abstract].
Shi, P., Yan, P., Yuan, Y., Nearing, M.A., 2004. Wind erosion research in China: past, present and future. Prog. Phys. Geogr. 28, 366–386.
Taylor, J.L., 2006. Negotiating the grassland: the policy of pasture enclosures and contested resource use in Inner Mongolia. Hum. Organ. 65, 374–386.
Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., Williams, R., 2009. Beneficial biofuels—the food, energy, and environment Trilemma. Science 325, 270–271.
Tong, C., Wu, J., Yong, S., Yang, J., Yong, W., 2004. A landscape-scale assessment of steppe degradation in the Xilin River Basin, Inner Mongolia, China. J. Arid Environ. 59, 133–149.
Turvey, C.G., Kong, R., 2010. Weather risk and the viability of weather insurance in China's Gansu, Shaanxi, and Henan provinces. China Agric. Econ. Rev. 2, 5–24.
Waldron, S., Brown, C., Zhao, Y., 2011. Developing the right institutional environment to deal with grassland degradation in China. In: Kemp, D.R., Michalk, D.L. (Eds.), Development of Sustainable Livestock Systems on Grasslands in North-western China. ACIAR Proceedings No. 134, Canberra, Australia, pp. 98–104.
Wang, C.J., Tas, B.M., Glindemann, T., Mueller, K., Schiborra, A., Schoenbach, P., Gierus, M., Taube, F., Susenbeth, A., 2009. Rotational and continuous grazing of sheep in the Inner Mongolian steppe of China. J. Animal Physiol. Animal Nutri. 93, 245–252.
Xu, Z., 1998. Go forward the 21st Century's Chinese Grassland Resources, 5. Grassland of China, pp. 1–8 [Chinese English abstract].
Xue, C., Zhang, W., 2009. The dynamic variation of grassland vegetation degeneration based on remote sensing modis data. Remote Sens. Land Resour. 2, 97–102.
Ye, L., van Ranst, E., 2009. Production scenarios and the effect of soil degradation on long-term food security in China. Glob. Environ. Change 19, 464–481.
Yu, M., Ellis, J.E., Epstein, H.E., 2004. Regional analysis of climate, primary production, and livestock density in Inner Mongolia. J. Environ. Qual. 33, 1675–1681.
Zhang, Z.T., 1990. Inner Mongolia Rangeland Resources (in Chinese). Inner Mongolia People's Publishing House, Hohhot, pp. 1–23.
Zhixin, X., Shuyou, L., 1989. Effect of winter utilization rate on vegetative characteristics of desert Steppe. J. Inn. Mong. Grassl. 12, 27–33.

Further reading

Liu, M., Hu, Y., Li, X., He, H., Xu, C., Zhang, W., 2007. Ecological footprint and biological capacity time series assessment for a forest region in northeastern China. Int. J. Sustain. Dev. World Ecol. 14, 493–496.
Zhongwu, W., Jiao, S., Han, G., Zhao, M., Willms, W., Hao, X., Wang, J., Din, H., Havstad, K.M., 2011. The impact of stocking rate and rainfall on sheep performance in a desert steppe. Rangel. Ecol. Manag. 64, 249–256.