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ORIGINAL ARTICLE

Optimization yak grazing stocking rate in an alpine grassland of Qinghai-Tibetan Plateau, China

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Abstract A simple yak (*Bos grunniens*) production model developed in this study was to evaluate the health of the intensive livestock production system in the three rivers headwaters region, on the Qinghai-Tibetan Plateau. An experiment conducted for 3 years showed that individual yak liveweight gain (kg/head) was negatively related to stocking rate (Sr) (head/ha). Yak liveweight gain per hectare (kg/ha) was modeled as a quadratic function of Sr, with an apparent optimum yak stocking rate (Sr_{op}). Following the model, the Sr_{op} rate was 1.67 heads/ha for the warm-season pasture (WSP), 0.72 head/ha for the cool-season pasture (CSP), and 0.63 head/ha for the yearlong periods grazing pastures, respectively. The corresponding maximum carrying capacity (when individual yak live weight gain was equal to zero) was 3.34, 1.44, and 1.26 head/ha for warm-season, cool-season, and yearlong periods grazing pasture, respectively. In comparison with modeled maximum stock carrying capacity, all the cold-season pasture in the three rivers headwaters region were overgrazed. By contrast, only 37.5 % of the warm-season rangeland area overgrazed. It indicated that reconstruction of the proportion of the seasonal rangeland area may be an effective strategy to prevent serious rangeland degradation in this alpine region. Moreover, adjustment of the stoking rate at optimum values may likely improve the income for local herders.

Keywords Alpine meadow · Seasonal grazing · Optimization management · Qinghai-Tibetan Plateau

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Introduction

The sustainable livestock production is crucial for Tibetan pastoralists who rely on healthy rangelands for their livelihood benefits (Zhou et al. 1995; Mishra et al. 2001; Wu and Du 2007; Harris 2010). Traditionally, pastoralists attempt to maximize livestock numbers to pursue economic wealth, even at the expense of rangelands and soils. In recent years, some herders have realized the grass and livestock balance due to the supervision and education provided by local Animal Husbandry Bureau (Wu and Du 2007). However, irrational overstocking of livestock is still widespread across the Tibetan Plateau which decreased ground cover and increased soil erosion (Mishra et al. 2001; Wu and Du 2007; Long et al. 2008; Harris 2010). Yaks (*Bos gunens*), as the dominant livestock on the QTP, play a crucial role in alpine grassland ecosystem functions and contribute to the animal husbandry economy. There was an estimated 3.3 million domestic yaks in the Qinghai Province, which accounts for 23.8 % of the global domestic yak population (14 million) and 25.4 % of the Chinese domestic yak population (13 million) (Dong and Li 2003). Apart from domestic livestock, there also harbors a number of wild herbivores, such as wild yak, horses, Tibetan antelope, and Tibetan gazelle. Livestock population pressures mean that many of the alpine grasslands are in a degraded state. Moreover, the degradation is increasing at a rate of 200 km^2/year in China (Harris 2010). The grassland degradation has led to impaired ecosystem services and low household incomes. Therefore, optimized management practices are required to balance the grassland and the livestock. Overgrazing has been a subject of much deliberation, and yet conclusive evidence about its occurrence has been remarkably difficult to find in this headwaters region (Shang and Long 2007; Shang et al. 2008). The relationship between stocking rates and livestock production was examined. Also the magnitude of overgrazing degree in seasonal grazing rangelands of the three rivers headwaters region on the Tibetan Plateau was assessed. This optimum model built on the grazing experiment may have implications for sustainable development in an alpine pastoral region.

Materials and methods

Study area

The headwaters region of the Yangtze, Yellow and Lancangjiang rivers is located on the Qinghai-Tibetan plateau. This region borders the southwestern Tibet Autonomous Region, abuts western Sichuan Province, and connects to the Haixi Mongolian and Tibetan Autonomous Prefecture in northwestern China (Fig. 1). Stocking rates were calculated by identified rangeland area and the number of sheep units assigned to 18 counties and 6 townships in this region.

The grazing experiment was conducted in Wosai Township of Dari County, in the southwest of Qinghai-Tibetan Plateau. It is located at longitude 99°30′21″–99°54′38″E, latitude 33°34′21″–33°49′19″N, with an average elevation of 4,000 m. The average air temperature is −1.3 °C with extremes of a maximum 24.6 °C in summer and minimum of 34.5 °C in winter. Average annual precipitation is about 590 mm, 80 % of which falls in the short growing season from May to September. There is no absolute frost-free period. The annual average sunlight is 2,331 h. The main plant species are: *Kobresia parva, Kobresia humilis*, *Elymus nutans*, *Potentilla anserina*, and *Poa alpigena* in moderately deteriorated state.

Experiment design

After a preliminary survey of the grassland productivity and community composition, stocking rates according to forage yield and experiential intake of growing yaks (2.4 kg DM/100 kg liveweight) were determined. To imitate the effect of stocking rates on yak production and rangeland productivity in three-river headwaters region, three grazing plots were fenced in a pasture of the Wosai Township, and grazed by the same set of four yaks, respectively, in different time periods: warm season (June–October), cold season (November–May) and the entire year. One control plot was set without grazing. These four plots were replicated three times. Two unfenced plots (100 × 100 m) were also identified to provide another local free yak-grazing treatment. "Relative utilization" is defined as percent removal of the current standing crop as opposed to "utilization", which is defined as percent removal of current year's growth (Short and Knight 2003). In the fenced plots, yaks grazed each of the 3 plots to 30 % (light grazing), 50 % (moderate grazing), 70 % (heavy grazing), and 0 % (control, no grazing) of relative utilization of the available forage, and grazed the unfenced plots to 90 % according to the relative utilization of forage vs. control in warm- and cool-season pastures. Thus, relative utilization of forage vs. control denotes that forage biomass ingested by yaks accounts for the percentage of control forage biomass from the same time period. Relative utilization was determined by balance methods outside and inside the cage using steel net. The current standing biomass was compared with the biomass of the control at the same time. The different stocking rates between warm- and cool-season pastures result from the nutrient status and digestibility of forage available for yaks during the grazing period (Zhao et al. 2000). Yaks were weighed on a monthly basis. To examine the actual rangeland stocking rates, with the goal of using our trial results to determine the status of carrying capacity in this region, the number of animals was summed and converted into the number of sheep units (Ren 1998), for adult yak herds, 1 yak equals 4 sheep units, and 1 sheep unit is a sheep that weights 40 kg; for growing yak herds, 1 yak equals 3.5 sheep units. The relationship between yak individual weight gain and stocking rates was described here using a simple linear function (Jones and Sandland 1974; Zhou et al. 1995; Wang et al. 1999; Dong et al. 2003a, b) and using a quadratic equation for yak liveweight gain per hectare and stocking rates (Jones and Sandland 1974; Crawley 1983; Wilson and Macleod 1991; Zhou et al. 1995; Dong et al. 2003a, b).

To gain the inflection (the maximum yak liveweight gain per hectare) optimum stocking rate, a quadratic model of Eq. (1) was also used:

$$\mathrm{Lg} = a - b \times \mathrm{Sr} \quad (b > 0). \tag{1}$$

where Lg = liveweight gain of individual yak (kg/head), and Sr = stocking rates. The intercept (a) of the y axis is often thought to denote nutrition level (forage quality),

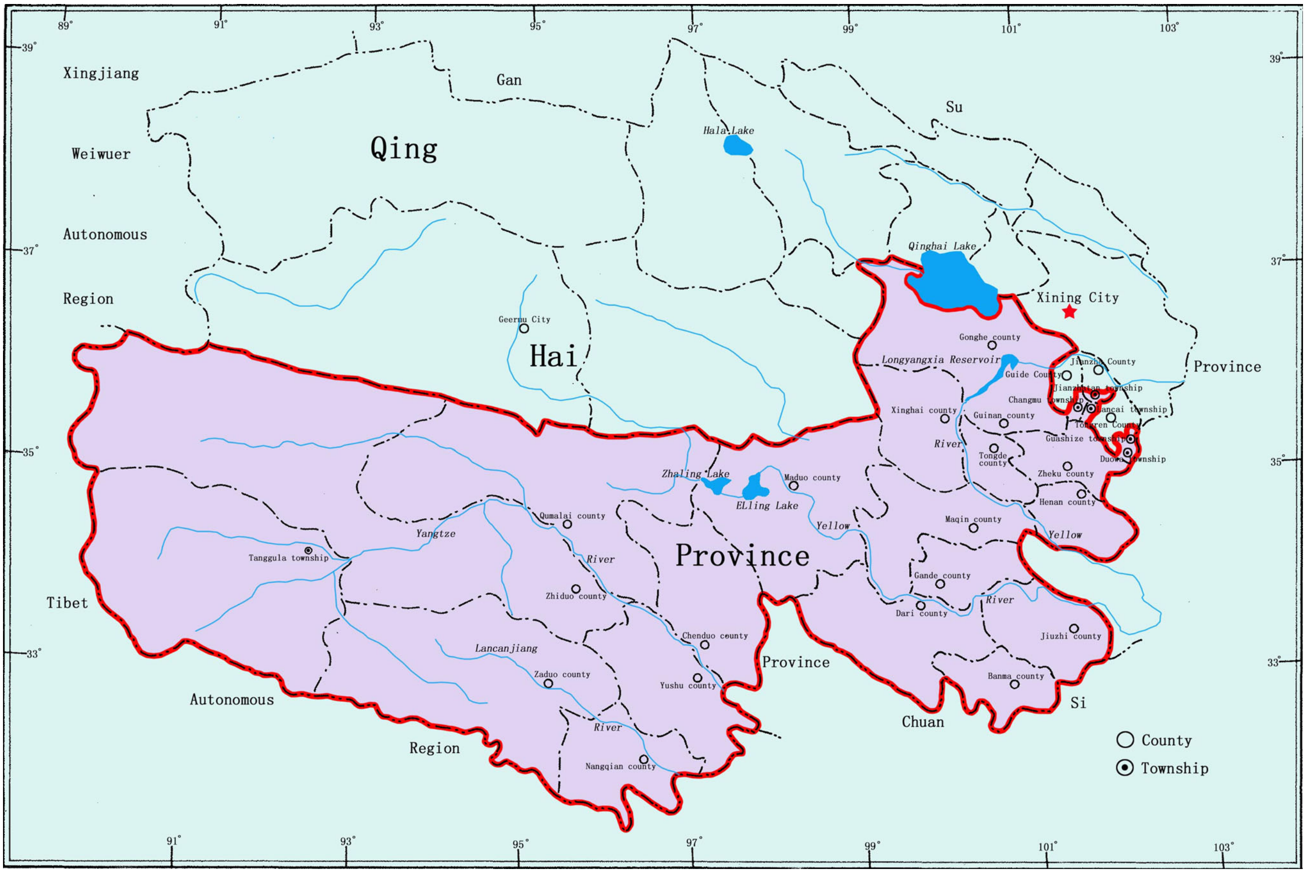

Fig. 1 Administrative division of Yangtze, Yellow and Lnacangjiang River headwaters region

while the slope (b) is thought to denote spatial stability and recovery potential of pasture under different stocking rates (Zhou et al. 1995; Dong et al. 2003a, b).

The modeled relationship between yak liveweight gain per hectare of rangeland and stocking rates was performed using the quadratic form of Eq. (1) to obtain Eq. (2). The regression equation is derived from data in Table 3, but the model is mathematically based on Eq. (1). Therefore, hereafter the regression equation (Eq. 2) was used, rather than the model equation, to decrease the error and make the results more relevant to this region.

$$\mathrm{Lg}_{ph} = a \times \mathrm{Sr} - b \times \mathrm{Sr}^2 \; (b > 0) \tag{2}$$

where $\mathrm{Lg}_{\mathrm{ph}}$ = yak liveweight gain per hectare of rangeland (kg/ha).

The vertices of the three curves represent the 'optimal' stocking rates ($\mathrm{Sr}_{\mathrm{op}}$) of the warm-season, cool-season, and yearlong periods, respectively, during which yak liveweight gain per hectare of rangeland will be maximized; this optimal stocking rate can be calculated as $a/2b$, which is half of the maximum carrying capacity, a/b; thus, the optimal carrying capacity is the stocking rate at which weight gain per hectare is maximal. Regression analysis showed that there was a quadratic relationship between yak liveweight gain per hectare and stocking rates for the warm-season, cool-season, and yearlong periods (Fig. 2). Equation (1) multiplied by Sr can give the relationship between yak liveweight gain per hectare of rangeland and Sr, yielding Eq. (2). This equation models the relationship between yak liveweight gain per hectare and stocking rates. The point of intersection ($\mathrm{Sr} = a/b$) between the regression straight line and the x axis denotes the point where liveweight gain of the individual yak is 0 when stocking rate equals a/b; this value is the maximum carrying capacity.

Results

Relationship between yak liveweight gain and stocking rate

Three years (1998–2000) grazing experiment showed that the liveweight gain per yak and stocking rates (Table 1) were negatively related (Fig. 2; Tables 2, 3). The intercept a_1 (71.86) and slope b_1 (20.33) in the warm season were greater than a_2 (24.53) and b_2 (16.93) in the cool-season grazing (Table 4), but there was no significant difference ($P > 0.05$).

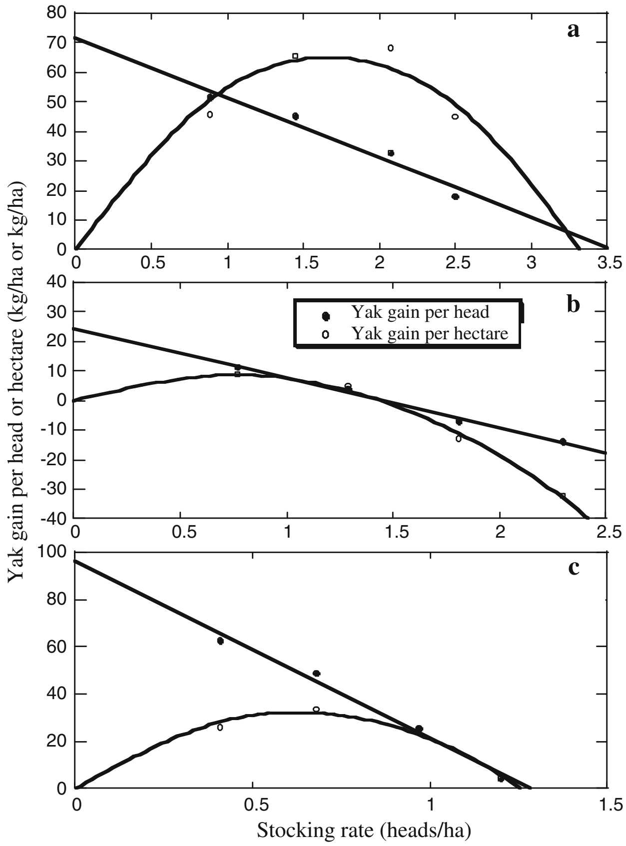

Fig. 2 Yak individual liveweight gain (Lg, kg/head) (*filled circle*) and yaks' total liveweight gain per hectare of rangelands (Lg_{ph}, kg/ha) (*open circle*) which are the averages of three grazing-seasons from 1998 to 2000, modeled as different functions of yak stocking rate in WSP (**a**), CSP (**b**) and in a yearlong grazing (**c**) in alpine meadow two-season rotational pastures of Yangtze, Yellow and Lancangjiang River headwaters region of Qinghai-Tibetan plateau. The value pointed by *arrow*, the vertex of *curve* represents the optimal stocking rate (Sr_{op}) at which Lg_{ph} is maximized in WSP (**a**), CSP (**b**) and in a yearlong grazing (**c**) respectively

Table 1 Trial design of pasture size, stocking rates for warm-season and cold-season treatments in this study

Treatments	No. of yak per plot	Pasture area (ha)		Stocking rates (heads/ha)	
		Warm-season pasture	Cold-season pasture	Warm-season pasture	Cold-season pasture
Light grazing	4	4.50	5.19	0.89	0.77
Moderate grazing	4	2.75	3.09	1.45	1.29
Heavy grazing	4	1.92	2.21	2.08	1.81
Control (no grazing)	0	1.00	1.00	0	0

Table 2 Regression equations between yak individual liveweight gain and stocking rates

	Regression equation	Correlation coefficient	Significance (*P*)
Warm-season pasture	Lg = 71.863–20.326 Sr	−0.9746	<0.01
Cold-season pasture	Lg = 24.53–16.93 Sr	−0.9968	<0.01
The whole year	Lg = 96.398–75.131 Sr	−0.9918	<0.01

Sr indicates stocking rate, and *Lg* represents yak individual liveweight gain which are means of 3 years in every grazing treatments

Optimum stocking rate and maximum carrying capacity

A quadratic model for seasonal and annual production was used; yak liveweight gain per hectare of rangeland decreases on either side of Sr_{op}, respectively (Fig. 2a–c). Yak liveweight gain per hectare of rangeland is lower than its value at the optimal stocking rate not only when $Sr > Sr_{op}$, but also when $Sr < Sr_{op}$. The optimal stocking rates (the maximum production stocking rate) (Sr_{op}) at which yak liveweight gain per hectare of rangeland will be maximized is 1.67 head/ha in warm-season pasture, 0.72 head/ha in cool-season pasture, and 0.63 head/ha for the yearlong periods in the alpine grassland of the headwaters region (Table 4).

Overstocking

Cool-season and yearlong pastures are both overstocked. The actual stocking rate was illustrated in the alpine meadow pastures from 18 counties and 6 townships of the headwaters region in relation to the calculated optimal stocking rate (Sr_{op}) and to the maximum carrying capacity ($2 \times Sr_{op}$) (Fig. 3). In the warm-season pasture, only 6 counties and 3 townships had stocking rates higher than Sr_{op} (1.67 heads/ha or 5.01 sheep units/ha); stocking rates in all counties and townships were substantially lower in the warm-season pasture than the calculated maximum carrying capacity of the rangeland (3.34 heads/ha or 10.02 sheep units/ha); in other words, they were overgrazed, not overstocked (Figs. 2a, 3a). In cool-season pasture, all counties and townships had stocking rates higher than Sr_{op} (0.72 heads/ha or 2.16 sheep units/ha); in other words, they were all overgrazed. Except for one township, stocking rates from all counties and townships were higher than the maximum carrying capacity of rangeland (1.44 heads/ha or 4.32 sheep units/ha); in other words, 18 counties and 5 townships were overstocked (Figs. 2b, 3b). As for annual grazing, except for one township, 18 counties and 6

Table 3 Regression equations between yaks' total liveweight gain per hectare of rangeland and stocking rates

	Regression equation	Theory equation	Correlation coefficient (R^2)	Significance (P)
Warm-season pasture	Lg_{ph} = 78.055 Sr–23.369 Sr^2	Lg_{ph} = 71.863 Sr–20.326 Sr^2	0.7945	<0.05
Cold-season pasture	Lg_{ph} = 24.228 Sr–16.799 Sr^2	Lg_{ph} = 24.53 Sr–16.93 Sr^2	0.9941	<0.01
The whole year	Lg_{ph} = 102.53 Sr–81.504 Sr^2	Lg_{ph} = 96.398 Sr–75.131 Sr^2	0.9693	<0.01

Sr indicates stocking rate, and Lg_{ph} represents yaks' total liveweight gain per hectare of rangeland, which are means of 3 years

Table 4 Maximum productive stocking rates for yaks (optimal stocking rates), maximum carrying capacity for two-season pastures and whole years

Pastureland	Optimal stocking rates				Maximum carrying capacity			
	Heads/ha		Sheep units/ha		Heads/ha		Sheep units/ha	
	Real	Theory	Real	Theory	Real	Theory	Real	Theory
Warm season pasture	1.67	1.77	5.01	5.31	3.34	3.54	10.02	10.62
Cold season pasture	0.72	0.72	2.16	2.16	1.44	1.44	4.32	4.32
The whole year	0.63	0.64	1.89	1.92	1.26	1.28	3.78	3.84

townships were all overgrazed, and 4 counties and one township were also overstocked (Fig. 3c). The analysis therefore suggested that 37.5 % of warm-season pasture may be overgrazed, and 100 % of the cool-season pasture may be overgrazed. In addition, 96 % of the cool-season pasture may be overstocked, and 96 % of pasture may be overgrazed and 21 % overstocked in the yearlong periods, i.e. grazed at stocking rates much higher than is biologically optimal.

Discussion

Livestock grazing is a global land-use activity with far-ranging societal and environmental impacts. It is the major biotic factor that influences pasture ecosystems (Yang et al. 2013). Although grazing effects the aboveground vegetation, soil physicochemical and microbial community properties of Tibetan alpine grassland have been documented in recent years (Klein et al. 2004, 2007; Luo et al. 2010; Yang et al. 2013). Few studies consider overgrazing effects on livestock liveweight gain and optimum stocking rate. There are different plant biomass, species composition and forage nutrient quality for two-season grasslands, which may have resulted in different maximum productive stocking rates for yaks (optimal stocking rates) and maximum carrying capacity. Our results showed that the warm-season pastureland presented the larger optimal stocking rates and maximum carrying capacity than the cold-season pastureland. Our results showed that the maximum carrying capacity of grazing pasture for yaks (Sr = a/b) and the optimal stocking rate for yaks (Sr = $a/2b$), mainly rely on the nutritional level of the pasture, the spatial stability in productivity or nutrition and the recovery ability of grazing

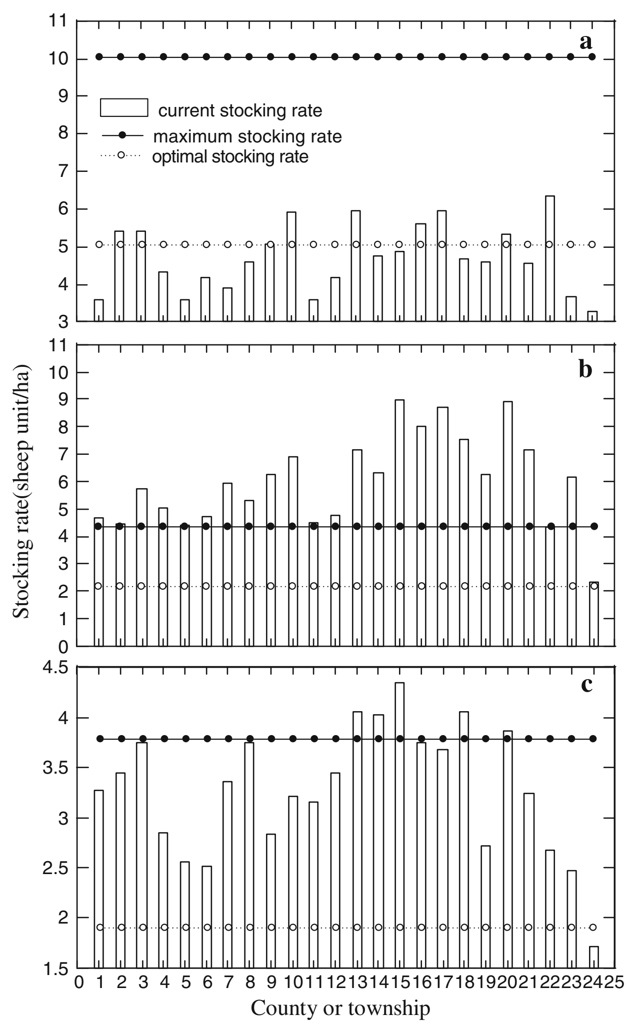

Fig. 3 Stocking rate in alpine meadow WSP (**a**), CSP (**b**) and the whole year (**c**) in 18 counties and 6 townships of this study

pastureland. Most researchers and officials discussed overgrazing or overstocking interchangeably in the Qinghai-Tibetan Plateau. In this study, the differences between overgrazing and overstocking were distinguished using a quantitative method. In warm-season pasture, grassland is overgrazed when the stocking rate is 1.67–3.34 head/ha or 5.01–10.02 sheep unit/ha; grassland is overstocking when the stocking rate is over 3.34 head/ha or 10.02 sheep unit/ha. So, this grassland was not overgrazed or overstocked under this stocking rate.

Compensation growth of grasses may override the grazing forage utilization due to soil abundant available resources under favorable climate (high temperature coupled with plenty precipitation) in the warm season. On the contrary, almost all of the nutrition released from animal dung or urine was lost during cold-season grazing when vegetation was dormant. Therefore, the warm-season grazing pasture can tolerate greater stocking rate than the cold-season pasture. However, the ratio for the maximum carrying capacity of warm:cool-season grazing pasture (2.3:1) was much lower in our study region than that for alpine swamp-meadow on the Qinghai-Tibetan plateau (ratio 9:1) (Table 4) (Zhou et al. 1995). This significant difference might be related to pasture types and soil hydrology. However, the regression equation partly explains the observed variation in yak individual weight gain because that inter/intra-annual variation in precipitation may cause variation in animal production.

In this alpine region, overgrazing has altered flora composition, destroyed riparian area, reduced wildlife habitat, and caused soil erosion and loss of biodiversity; consequently deteriorates ecosystem services (Ma et al. 2002; Zhou et al. 2003; Wang 2003; Dong et al. 2003a, b; Wu et al. 2009). The indirect impact on soils function due to overgrazing is probably even more serious than the direct effect on plants (Holechek et al. 1995; Wang 2003; Zhou et al. 2003). However, it may be assumed that the local human communities know best how to manage their rangeland, as this knowledge has accumulated over generations of experience. These results indicated that pastures in this headwaters region are overstocked.

Conclusion

Our results indicated that efficiency of the livestock production was greatly dependent on the stocking rates of the grazing regime on the Tibetan Plateau. According to the optimization model developed in the current study, most of counties and townships in the three rivers source region were overgrazed in the cool-season pasture, but not in the warm-season pasture. Therefore, efforts of improved management should be directly paid in the cool season pastures. Curtailing or prohibiting livestock grazing in the cold season pastures would affect household incomes in short-term. Adjustment of the proportion of seasonal grazing area to optimize the stocking rates would be an alternative strategy, which will realize 'win–win' outcomes for grasslands and households.

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