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The Rangeland Livestock Carrying Capacity and Stocking Rate in the Kailash Sacred Landscape in China

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Abstract: Maintaining the health and productivity of rangelands by controlling the livestock stocking rate to remain within carrying capacity is of significance to ensure sustainable management of rangeland ecosystems. But we know little about the safe carrying capacity in particular rangeland landscapes. This has hampered efforts to use rangelands in a risk-averse manner in fluctuating rainfall environments, and especially in arid and semiarid areas. To address this lack of information, we took Kailash Sacred Landscape in China (KSL-China) as our study site and used remote sensing data, meteorological data and statistical data from 2000 to 2015 to analyze rangeland carrying capacity, stocking rate, and major influencing factors. Rangeland carrying capacity presented an increasing trend, while stocking rate was gradually decreasing, resulting in an increase of carrying rate in the study area. The increased carrying capacity was closely related to increased rainfall. Stocking rate declined owing to government regulations, particularly implementation in 2004 of the national policy of *Returning Grazing Land to Grassland*. There was a sharp reduction of livestock number below 200 000 standard sheep units (SU) after 2005. The decrease of stocking rate had a stronger effect on rangeland carrying rate than did the increase of carrying capacity. Ecosystem restoration programs have provided subsidies to pastoralists to encourage them to reduce livestock numbers. Our findings suggest that a safe rangeland carrying capacity is ca. 170 000 SU in KSL-China. There is a carrying capacity surplus of ca. 50 000 SU for safe animal husbandry development in the study area. More importantly, future climate warming and increases in grazing may jointly play a key role in affecting rangeland carrying capacity.

Key words: Kailash Sacred Landscape in China; rangeland; net primary productivity; safe carrying capacity; stocking rate

1 Introduction

Rangeland is an important component of terrestrial ecosystems and lays the foundation for animal husbandry and sustainable livestock development. Besides supplying forage for livestock, rangelands provide critical ecosystem goods and services for human beings. However, rangelands are prone to degradation due to overgrazing. Excessive grazing is one of the key disturbances leading to rangeland degradation (Akiyama and Kawamura, 2007). Widespread degradation has made more urgent than ever the need to restore rangelands degraded from overgrazing and keep livestock populations within livestock carrying capacity (Xiong *et al*. 2016). Hence, maintaining the health and productivity of rangelands by controlling the livestock stocking rate to remain within carrying capacity is imperative to ensure sus-

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tainable development in ecologically fragile regions.

Rangeland productivity is variable, determined mainly by rainfall. Distinct rainfall variability in terms of amount and seasonal distribution dramatically affects forage availability and consequently leads to substantial fluctuations in livestock carrying capacity (O'Reagain and Scanlan, 2013). As such, rainfall variability represents a major challenge to sustainable grazing management in rangelands, especially in variable, vulnerable semiarid and arid regions. Therefore, matching stocking rates with forage supply and maintaining stocking around the safe long-term carrying capacity maintains land condition and maximizes long-term profitability (O'Reagain *et al*., 2014). However, stocking rates should be varied in a risk-averse manner as pasture availability varies from year to year. The carrying capacity and profitable stocking rate are often unknown factors in different rangelands.

Australia has long and rich experience of assessing carrying capacity and determining appropriate stocking rates in its northern rangelands. There is considerable evidence to indicate that low to moderate rates of pasture utilization have maintained land condition (McKeon *et al*. 2009). A nearly 30-year study showed that pasture conditions were maintained at a 30% utilization rate of dry-season standing forage while a 50% utilization rate proved unsustainable with a marked decline in pasture conditions after 20 years (Orr and Phelps 2013). Overall, available evidence shows that in the extensive grazing lands of northern Australia a constant, moderate stocking at around the long-term carrying capacity maintains and improves land conditions and is more profitable than heavy grazing (O'Reagain *et al*. 2009; O'Reagain and Bushell 2011; O'Reagain *et al*. 2014). Evidence indicates that maintaining the stocking rate around long-term carrying capacity is most favorable for the livestock and to achieve the sustainable management goal.

Overgrazing is common in Chinese rangelands which are degraded. The *Returning Grazing Lands to Grasslands* (RGLG) program was implemented in 2003 with fenced off grazing exclusion areas, rangeland oversowing and sown pasture in temperate and alpine rangelands. The release of rangeland from grazing by enclosure can restore rangeland conditions in terms of soil quality, community structure and ecosystem functioning (Xiong *et al*. 2014; Xiong *et al*., 2016). The government's rangeland reward mechanism is an effort to reduce livestock population in overgrazed areas and maintain the forage-livestock balance (matching stocking rates with forage supply). The focal points of future RGLG implementation are rotational grazing, seasonal grazing exclusion, and matching stocking rate with forage supply while remaining within livestock carrying capacity. However, these programs are based on national-scale planning. Long-term carrying capacities on a regional scale are unknown and, therefore, county or landscape level assessments are urgently needed.

Assessment of long-term carrying capacity provides a basis for determining a safe stocking rate and an optimal rangeland management program. Accordingly, we use satellite data, meteorological data, and statistics for the Kailash Sacred Landscape in China from 2000 to 2015 as a case study to estimate long-term rangeland carrying capacity and analyze the main factors influencing carrying capacity. The objective of this study is to assess dynamic livestock carrying capacity, stocking rate and the influencing factors for the past 15 years. The purpose is to provide a better understanding of safe rangeland carrying capacity at a county landscape scale. This can benefit decision making for sustainable management of the forage-livestock system and development of the local husbandry sector.

2 Materials and methods

2.1 Study area

The transboundary Kailash Sacred Landscape (KSL) extends over an area of approximately 31 000 km^2, the apex of which is Mount Kailash (called Gang Rinpoche in Tibetan), including territory in the western Tibet Autonomous Region of China, India's northern state of Uttarakhand, and far western Nepal. The landscape is sacred to five religions, and contains important wildlife sanctuaries and biodiversity hotspots (ICIMOD, 2012). KSL is the flagship transboundary conservation initiative of the International Center for Integrated Mountain Development (ICIMOD). The KSL in China (hereinafter KSL-China) is distributed for the most part in Burang County, Tibet Autonomous Region (80°27′-82°30′E, 30°00′-31°13′N; Fig. 1) with an area of 10843 km^2. The area has a typical alpine and arid climate, with annual mean temperature of 2-5°C and annual rainfall of 100-250 mm. It is composed of a typical agro-pastoral landscape of Karnali watershed and alpine rangeland landscape in Manasarovar watershed. Rangeland is mainly distributed in a high-altitude Manasarovar watershed (with average altitude of 4700 m) and part in a lower-altitude Karnali watershed (average 4000 m). The major landscapes in this region include rangelands, deserts, lakes, barren lands, glacier, and croplands, etc. with rangeland area occupying more than 60% of total area. Alpine rangelands, including alpine meadows dominated by *Kobresia pygmaea, K. humilis and Carex moorcroftii* and alpine desert steppes dominated by *Stipa purpurea, S. glareosa, S. subsessiliflora* and *Ceratoides lateens* etc. are widely distributed (Wu *et al*. 2013).

2.2 Data gathering and analysis

The data used in the study includes MOD17 (http://www.ntsg.umt.edu/project/mod17) which were provided by the Numerical Terradynamic Simulation Group (NTSG) of The University of Montana, at a spatial resolution of 1 km, in GeoTIFF format, Geographic Lat/Lon, WGS1984, from 2000 to 2015. The dataset provides information about annual

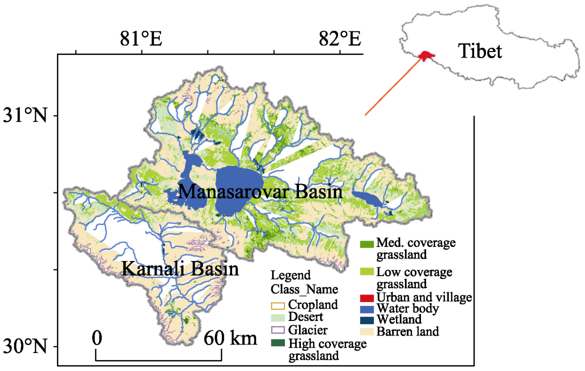

Fig.1 Location and landscapes of Kailash Sacred Landscape

net primary production, and contains the following improvements: temporal infilling of cloud-contaminated pixels and consistent forcing meteorology. Details of dataset improvements can be found in Zhao *et al*. (2005), and in the supplement of Zhao and Running (2010). Statistical data include livestock and meat consumption of Burang County from 2000 to 2016, provided by the China National Knowledge Internet (www.cnki.net). Meteorological datasets (rainfall, temperature) from 1973 to 2013, were obtained from China Meteorological Data Sharing Service System (https://cdc.cma.gov.cn).

The MOD17 data were processed via regions of interest (ROIs, vector border of the study area) based on ENVI 4.8 version software. The NPP data were used to calculate rangeland livestock carrying capacity from 2000 to 2015.

2.2.1 Cropland mask

To exclude the influence of cropland, areas of cropland extracted from the Landsat images in 2008 were used to mask cropland patches in calculating rangeland carrying capacity.

2.2.2 Carrying capacity

Carrying capacity, based on an equilibrium concept, is the livestock population that can be supported by resources in long-term equilibrium. A safe livestock carrying capacity is quantified as the number of adult equivalents (standard sheep unit, SU) that can be carried on a rangeland in the long run without any decrease in pasture conditions (Scanlan, *et al* 1994, Desta and Coppock, 2002). Carrying capacity is usually estimated based on forage production which is evaluated on a large scale using data for the remote-sensed net primary production of rangeland.

According to the national standard for calculating rangeland carrying capacity (*Rangeland Standard*, NY/T635-2015) published by the Ministry of Agriculture of the People's Republic of China, the rangeland forage production is,

$$Y = Y_p \times A \tag{1}$$

where Y is forage yield in a certain area (kg), Y_p is forage yield per unit area (kg.km^{-2}), and A is land area of rangeland (km^2).

With respect to the availability of forage, utilization rates are used to calculate dry forage yields of different rangelands. The rangeland utilization rate is the percentage of forage that can be used for livestock and satisfies the condition of not causing rangeland degradation. In this paper, we use the utilization rates of 20% in desert-steppe, 40% in steppe, and 50% in meadow as per NY/T635-2015.

The formula for calculating standard dry forage yield is defined as,

$$F = \sum_{i=1}^{n} Y_i \times U_i \times C_i \tag{2}$$

where F is the yield of standard dry forage (kg), Y_i , U_i and C_i are the forage yield (kg), utilizable rate (%) and conversion coefficient of standard dry forage respectively in a certain grassland type. In this paper, the conversion coefficients are 0.85, 0.9 and 1.0, respectively, in alpine desert-steppe, steppe and meadow.

A proper rangeland carrying capacity is calculated as,

$$C_c = \frac{F}{I \times D} \tag{3}$$

in which C_c is a proper livestock number that rangeland can bear (SU), F the yield of standard dry forage (kg), I the daily intake for a standard sheep unit (1.8 kg/d), and D grazing days (365 days) in this paper.

2.2.3 Stocking rate

The stocking rate represents a real number of livestock in a certain grassland area during a certain period of time. A real stocking rate should include both all kinds of large herds and meat consumption. The formula for calculating the approximate stocking rate is defined as:

$$S_r = S_c + S_s + S_y + S_m \tag{4}$$

in which S_r is a real number of livestock (standard sheep unit), S_c the number of conversion from breeding stock of yak within a year (SU), and S_s the number of sheep stock within a year.

$$S_y = \frac{C \times B}{I \times D} \tag{5}$$

where S_y is the number of conversion from yak meat production within a year, C is the conversion coefficient of yak meat production into dry matter (C=71.38), B the yak meat production (kg), I the daily intake for sheep (1.8 kg/d), and D the grazing days (365 days).

$$S_m = \frac{C \times M}{I \times D} \tag{6}$$

in which S_m is the number of conversion from mutton production within a year (standard sheep unit), C the conversion coefficient of mutton production into dry matter (C=65.07), M the mutton production (kg), I and D as defined above.

2.2.4 Carrying rate

Carrying rate (C_r) shows whether or not grazing activity exceeds carrying capacity in a certain area during a certain period of time. Overgrazing of rangeland is indicated when $C_r < 0$, and a surplus is indicated when $C_r > 0$. C_r is defined as:

$$C_r = \frac{C_c - S_r}{C_c} \quad (7)$$

in which C_r is proper carrying capacity, and S_r is real stocking rate.

2.2.5 Data standardization

For analyzing the correlation between carrying capacity and influencing factors, data is standardized as,

$$z_i = \frac{x_i - \min x}{\max x - \min x} \quad (8)$$

where z_i represents a standardized variable without a unit, x_i is the value of a variable at time i, max x and min x are the maximum and minimum x value during a period of time. This formula can simplify and parameterize the values when measured units are involved.

3 Results

3.1 The livestock carrying capacity and stocking rate in KSL-China

The rangeland aboveground net primary productivity (ANPP) is higher in the Manasarovar Basin than in the Karnali Basin (Fig. 2). The Manasarovar Basin is the main landscape for grazing and the concentration of livestock population. The rangeland livestock carrying capacity in KSL-China varied from year to year, ranging from a low of 104,139 in 2000 to a high of 304,199 in 2013. However, the stocking rate in the study area had relatively little fluctuation, especially after 2005 (Fig. 3). After 2005, the number of livestock decreased sharply to 200,000 SU. To maintain the balance between forage production and livestock, livestock population in KSL-China maintained a relatively constant stocking rate from 2005 on (Fig. 3).

The carrying rate tended to increase due to increasing carrying capacity and decreasing stocking rate from 2000 to 2015. From 2010 on, carrying rate became positive, indicating that the issue of overgrazing had been reversed and the situation improved (Fig. 3). The 15-year mean rangeland carrying capacity in KSL-China is about 171,000 SU. But from point view of forage-livestock equilibrium, a maximum livestock number is 201,300 SU, which can be sustained if carrying rate is controlled at a critical point of zero in Fig. 4.

To explore spatial changes in rangeland carrying capacity of KSL-China, the livestock carrying capacities were calculated separately in Karnali watershed and Manasarovar watershed. The aboveground net primary productivity in the Manasarovar watershed was markedly higher than that in the Karnali watershed (Fig. 2). Likewise, it was clearly shown that rangeland carrying capacity was significantly higher in Manasarovar watershed than in Karnali watershed, with average carrying capacities of ca. 59,500 SU in the Karnali watershed and about 111,500 SU in the Manasarovar watershed (Table 1). Moreover, Table 1 shows that the rangeland carrying capacities in Karnali watershed and Manasarovar watershed both presented increasing trends from 2000 to 2015.

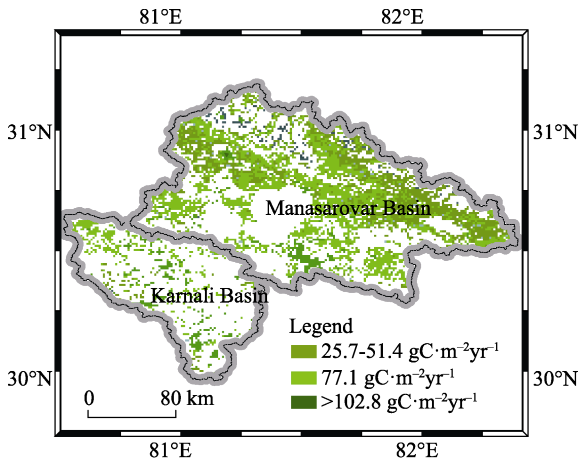

Fig.2 The spatial patterns of mean aboveground net primary productivity in KSL-China

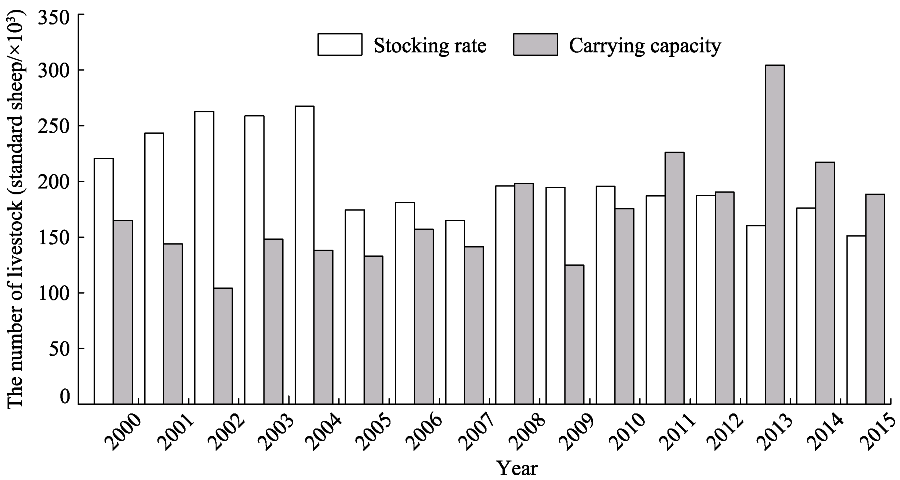

Fig.3 The dynamics of carrying capacity and stocking rate in KSL-China

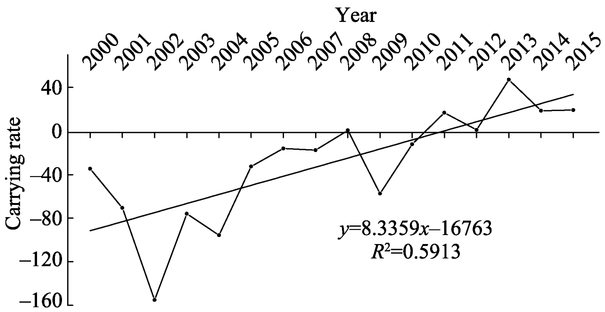

Fig.4 The changing trend of carrying rate in KSL-China from 2000 to 2015

Table 1 The livestock carrying capacities in Karnali watershed and Manasarovar watershed

Year	Carrying capacity (standard sheep unit)		
	Karnali Watershed	Manasarovar Watershed	KSL-China
2000	56 198	107 597	163 795
2001	49 728	92 892	142 620
2002	39 192	63 705	102 897
2003	51 411	95 649	147 060
2004	46 081	90 780	136 861
2005	43 183	88 492	131 675
2006	55 394	100 451	155 845
2007	50 685	89 377	140 062
2008	57 058	140 020	197 078
2009	47 027	76 507	123 534
2010	67 077	107 328	174 405
2011	71 356	153 293	224 649
2012	61 585	127 763	189 348
2013	98 772	204 185	302 957
2014	78 901	137 110	216 011
2015	78 323	108 946	187 269
Average	59 498	111 506	171 004

Among the grassland types, the increase of carrying capacity was greatest in alpine meadow, followed by alpine steppe, and then alpine desert-steppe (Fig. 5). Furthermore, carrying capacity fluctuated dramatically in alpine meadow, but did not change significantly in alpine steppe and desert steppe during the period from 2000 to 2015. This indicates that alpine meadow contributed to more forage production than other types of rangeland especially in years of high rainfall.

3.2 The factors influencing carrying capacity and stocking rate

The livestock carrying capacity was significantly influenced by annual rainfall (P<0.05, Fig. 6), but stocking rates did not vary temporally with varying carrying capacity.

The decreased stocking rate played an important role in improving carrying rate. Through standardization, carrying rate was negatively correlated with stocking rate, while positively correlated with carrying capacity (Fig. 7).

Although annual livestock carrying capacities were significantly correlated with the changes of annual rainfall, among the grassland types, carrying capacities was significantly correlated with rainfall only in alpine desert-steppe and in meadow (Table 2). The analysis of rangeland carrying capacity shows that alpine meadow had the highest increase

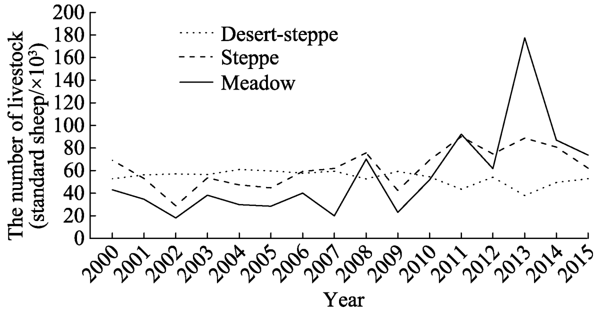

Fig.5 The dynamics of livestock carrying capacity in different types of rangelands

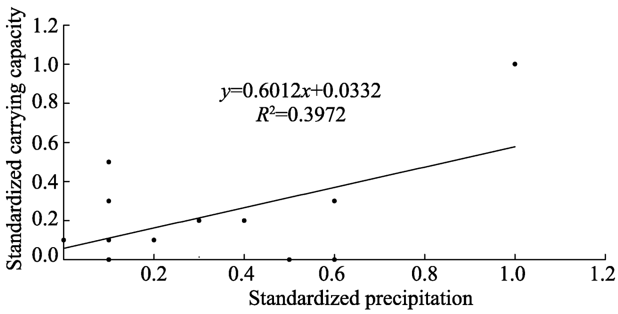

Fig.6 The correlation between normalized rangeland carrying capacity and annual rainfall

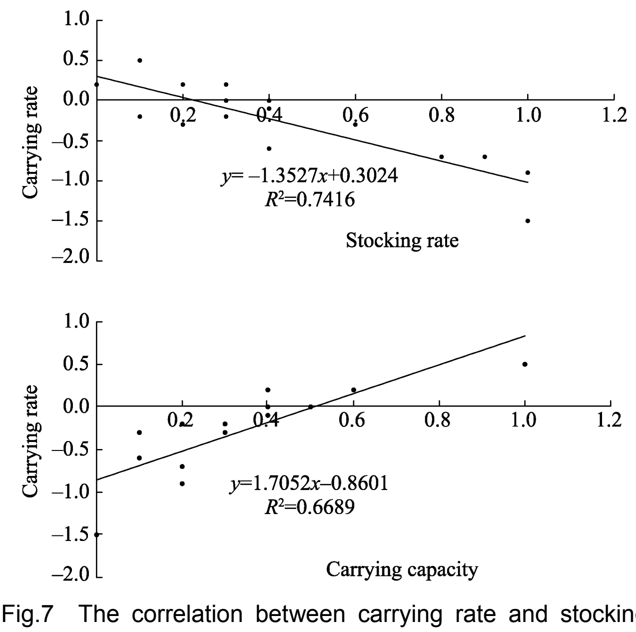

Fig.7 The correlation between carrying rate and stocking rate, carrying capacity

of carrying capacity, while desert-steppe showed decreased carrying capacity in the past 15 years.

Table 2 The liner correlation between rangeland livestock carrying capacity and rainfall

	Desert-steppe	Steppe	Meadow
Rainfall	–0.534*	0.253	0.630*

Note: * means P<0.05

4 Discussion

4.1 The change of carrying capacity and safe carrying capacity

The KSL-China is located in the western Tibetan Plateau, an area with low annual rainfall. The vegetation that dominates alpine steppe and desert steppe is susceptible to climate change, especially to annual rainfall variations and frequent drought events. Our study showed that livestock carrying capacity fluctuated in the KSL-China and was closely correlated with annual rainfall during the past 15 years. Our results are consistent with the findings that forage growth and spatio-temporal distribution in rangelands are driven by rainfall and tend to be extremely variable (Ellis 1994). However, several studies have shown that grazing also has substantial impact on rangeland production, and consequently on rangeland carrying capacity (Fernandez-Gimenez and Allen-Diaz 1999; Fynn and O'Connor 2000). Especially in arid areas, rangelands are prone to degradation and a decrease of livestock carrying capacity under heavy and continous grazing (Campbell *et al*. 2006).

Our study provides a dynamics estimation of livestock carrying capacity for the past 15 years in KSL-China. The long-term mean carrying capacity was assumed to be the safe carrying capacity because it reflected fluctuating climate change in climate cycling. Although the maximum carrying capacity is nearly 200,000 SU, safe livestock carrying capacity should be kept at level of 170,000 SU. But the statistical data for stocking rate was about 120,000 SU in Burang County in 2016. The carrying rate, the balance of carrying capacity and stocking rate, indicated a surplus of carrying capacity for livestock production after 2010. Currently, the surplus for livestock breeding is about 50,000 SU.

Climatic fluctuation is the main cause of fluctuations in rangeland carrying capacity in the Kailash region. Moreover, the decreasing rainfall and increasing evapotranspiration caused by climate warming both exacerbate drought in this region. In recent years, drought induced by climate warming has become much more frequent. According to meteorological data, climate warming in the Kailash region has shown an increasing trend during the last 30 years. Xue *et al.* (2009) also found that surface soil temperature in the Qinghai-Tibetan Plateau increased at an average rate of 0.6 °C per decade from 1980 to 2005, and that thawing days on the surface increased by 60 days from 1983 to 2001. This indicates that climate warming and permafrost thawing have caused desertification in grazing regions of the Qinghai-Tibetan Plateau. As a consequence of increasing temperatures, herdsmen are going to the high altitude pastures much earlier than in the past (Yi *et al*., 2012). Moreover, growing season changes caused by climate warming also impact plant and animal ecosystems (Linderholm 2006).

Our results showed that alpine meadow contributed more forage production in high rainfall years, while primary productivity in desert-steppe and steppe remain unresponsive to increased rainfall. Therefore, the increase of primary productivity in alpine meadow is more sensitive to rainfall, although fluctuations of forage supply are caused by variable rainfall in different grassland types. Piao *et al*. (2006) also found that the largest annual net primary productivity increase appeared in alpine meadows in the Qinghai-Tibetan Plateau. As for net primary productivity in the infertile steppe and desert-steppe, it may be relatively unresponsive to rainfall change due to resource (nutrient) limitations. Because water and nutrients are colimitation resources, an increase of rainfall alone may have relatively little effect on production in plant communities (Eskelinen and Harrison 2015).

4.2 The change of stocking rate and influencing factors

Oesterheld *et al*. (1992) reported that herbivore trophic levels, including biomass, consumption and productivity, were significantly correlated with primary forage productivity across a broad range of terrestrial ecosystems. But stocking rates did not track temporally variable carrying capacity in our findings. Compared with annual changes in rangeland carrying capacity, seasonal constraints are more important for livestock grazing intensity in natural grasslands (Fetzel *et al*. 2017). Furthermore, researchers stressed spatio-temporal variation in forage quality and quantity and argued that whilst rainfall drove increases in livestock numbers, crashes might occur during droughts (Ellis and Swift, 1988). Nonetheless, it has been pointed out that livestock numbers are relatively unresponsive to single year droughts, while multiple year drought events can cause losses in livestock numbers (Illius *et al*. 1998).

The stocking rate showed a decreasing trend in KSL-China, and there was an especially marked shift in livestock number after 2005. To maintain a healthy rangeland ecosystem, government subsidies for slaughter were implemented nationwide for ecological conservation. Harris (2010) reported that ecosystem restoration policies that use subsidies to reduce livestock numbers in the Qinghai- Tibetan plateau have been implemented. Implementation of the program *Returning Grazing land to Grassland* has been underway in Burang County since 2004. Du (2004) suggested that degradation of grassland by overgrazing could increase potential evapotranspiration level, thereby enhancing climate warming and the degradation process. Consequently, livestock population reduction is a conservative strategy to maintain a relatively constant stocking rate, in order to avoid livestock losses and grassland degradation.

Besides the impacts of climate change and human regulation, other influencing factors also put pressure on rangeland carrying capacity and stocking rate. For example, shrub encroachment is known to occur as a result of the selective overgrazing of grasses by livestock; shrub encroachment reduces the carrying capacity of arid grasslands for livestock (Jeltsch *et al*. 1997). Moreover, forage competition between small mammals and livestock also can influence forage availability and livestock densities (Retzer and Reudenbach 2005).

4.3 Limitations of carrying capacity assessment and future direction

For calculating rangeland carrying capacity, many variables in this paper were given certain parameters as per national standards. For instance, managing pastures to get the maximum benefits from them is crucial to meet the needs of local herders. But it is not possible to have maximum weight gain per individual cattle and maximum gain for the pasture. Because there is a lack of sufficient understanding of current socio-ecological systems to identify ultimate and proximate drivers of pastoralist behavior, policy initiatives aimed at sustainability may fail. Ho and Azadi (2010) also suggested that management, social, and economic issues should be presented in rangeland studies. However, we have to point out that there are few data to meet this need due to data shortages in the present period. Rangeland management should take into account many of these variables mentioned above, in order to maintain the balance between forage availability and the needs of increasing livestock population in the long run.

5 Conclusions

Rangeland primary forage production and consequently livestock carrying capacity were mainly controlled by rainfall, but stocking rate was regulated by government policy set forth in *Returning Grazing Land to Grassland*, particularly since the year 2005. Therefore, the stocking rate did not follow the change trend of livestock carrying capacity in KSL-China. In order to maintain the balance between forage supply and livestock production, livestock population in KSL-China has maintained a relatively constant stocking rate since 2005. Major recommendations for rangeland management are to match stocking rates with forage supply and keep stocking rate within long-term safe livestock carrying capacity of 170,000 SU in KSL-China. Currently, livestock population in KSL-China does not exceed the rangeland carrying capacity. There is still surplus for the development of animal husbandry. And yet, rangeland carrying capacity is very susceptible to climate change and grazing in the long-term. The stocking rate should be maintained at a relatively constant number to avoid livestock losses and grassland degradation caused by overstocking and overgrazing. To this end, a long-term monitoring system on carrying capacity change is necessary to improve understanding of the changing trend and its impact on rangelands.

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冈仁波齐圣地景观区的草地承载力和载蓄率变化

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摘　要：将草地载畜率控制在草地承载力范围内，维持草地的健康和持续生产力是草地生态系统可持续利用的基础，但目前对特定景观的安全承载力还知之甚少，这降低了在降雨年际波动较大环境，特别是干旱和半干旱区草地利用过程中规避风险的能力。采用 2000–2015 年的遥感数据、统计数据和气象数据，基于中国草地承载力和载蓄量计算标准，分析了冈仁波齐草地承载力和载蓄率的变化趋势和影响因素。结果表明：2000-2015 年草地承载力呈增加趋势，而载蓄率呈逐渐减少的趋势，二者共同作用导致研究区承载率呈增加趋势。研究期间草地承载力的增加与降水的增加有关，而载蓄率的减少则主要受人类决策的调控，尤其是 2005 年后受国家退牧还草政策的影响，牲畜量明显少于 20 万标准羊单位。就对研究区承载率的影响程度而言，载蓄率的减少比草地承载力的增加影响更大，这和国家生态恢复项目通过补贴牧民来减少载蓄量有关。此外，研究结果表明研究区相对合适的草地承载力为 17 万标准羊单位。未来气候变暖和放牧压力仍是影响该区域草地承载力的主要因素，通过长期的草地承载力监测能够更好的为草地管理提供依据。

关键词：冈仁波齐圣地景观；草地；牧草生产力；承载力；载蓄率