Journal of Arid Environments 74 (2010) 1–12

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Review

Rangeland degradation on the Qinghai-Tibetan plateau: A review of the evidence of its magnitude and causes

R.B. Harris*

Department of Ecosystem and Conservation Sciences, College of Forestry, University of Montana, Missoula, MT 59812, USA

ARTICLE INFO

Article history:
Received 24 November 2008
Received in revised form
9 June 2009
Accepted 15 June 2009
Available online 10 July 2009

Keywords:
Climate change
Economic incentives
Grassland degradation
Livestock
Pastoral policy
Qinghai-Tibetan plateau

ABSTRACT

Rangelands of the Qinghai-Tibetan plateau (QTP), although sparsely populated and contributing little to China's overall economy, play an important environmental role throughout Asia. They contain high biodiversity values and can also potentially provide China with a source of cultural and geographic variety in the future. Chinese government reports paint a gloomy picture, considering vast portions of the QTP degraded and blaming irrational overstocking of livestock as the principal culprit. Global climate change, population increases, and "rodent" damage are also invoked as causes of rangeland degradation. In contrast, some Western observers claim that traditional pastoral practices were sustainable, and identify either previous or more recent state policies as the cause of degradation. Chinese governments at national and provincial levels have initiated a number of sometimes-conflicting and confusing policies aimed, at least nominally, at restoring rangeland productivity. On the basis of a comprehensive literature review, I argue that the extent and magnitude of rangeland degradation on the QTP remains largely unknown because monitoring programs have been subjective and poorly documented. Further, I argue that causes of degradation remain uncertain, often because hypotheses have been articulated too vaguely to test. No phenomena that have been hypothesized as contributing to rangeland degradation on the QTP currently enjoy unequivocal support. Where over-stocking is clearly causing damage, we lack sufficient understanding of current socio-ecological systems to identify ultimate and proximate drivers of pastoralist behavior, and thus policy initiatives aimed at sustainability may well fail.

1. Introduction

Rangeland degradation is a global concern, affecting not only pastoralists who rely on healthy rangelands for their survival but others who suffer from resultant hydrological disturbances, dust storms, commodity scarcity, and social consequences of uprooted people. Rangeland health also affects biodiversity directly and indirectly because all native flora and fauna have adapted to the long-term evolutionary forces that have shaped these rangeland environments. Livestock grazing is the dominant form of land use in arid biomes worldwide, and grazing lands of the Qinghai-Tibetan plateau (QTP; Fig. 1) in the People's Republic of China are located in the source area for most of Asia's major rivers, upstream and upwind of upwards of 40% of the world's human population (Foggin, 2008). Pastoralism is also the dominant land-use in the other major biomes of western China (e.g., Mongolian Plateau, Tarim, and Dzungarian Basins), as well as in adjacent Mongolia, Kazakhstan, Kyrgyzstan, and Tajikistan, where land degradation is a similarly serious issue.

Awareness by Chinese scientists and policy-makers of the impacts of rangeland degradation on the QTP increased in the late 1990s as several disasters occurred, including Yangtze River floods that killed thousands of residents downstream and cost billions of dollars in economic losses, the Yellow River running dry increasingly often, and dust-storms and sand-storms originating in western rangelands that affected the health and economic well-being of millions of city-dwellers in China's east. Although lacking clear documentation and differing in specifics, Chinese scientific papers and government policy statements are unanimous in viewing the QTP as having become increasingly degraded in recent decades (Yan, 2001; Wang et al., 2005; Zhao and Zhou, 2005). A frequently repeated statistic is that 90% of China's grasslands are degraded to some extent, and that degradation is increasing at a rate of 200 km^2/yr (State Council, 2002).

Causes for rangeland degradation are generally attributed to a combination of over-stocking of livestock, unscientific livestock management, historical-cultural impediments to adopting modern livestock management concepts, global climate change, and

* Tel.: +1 406 542 6399.
E-mail address: rharris@montana.com

0140-1963/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jaridenv.2009.06.014

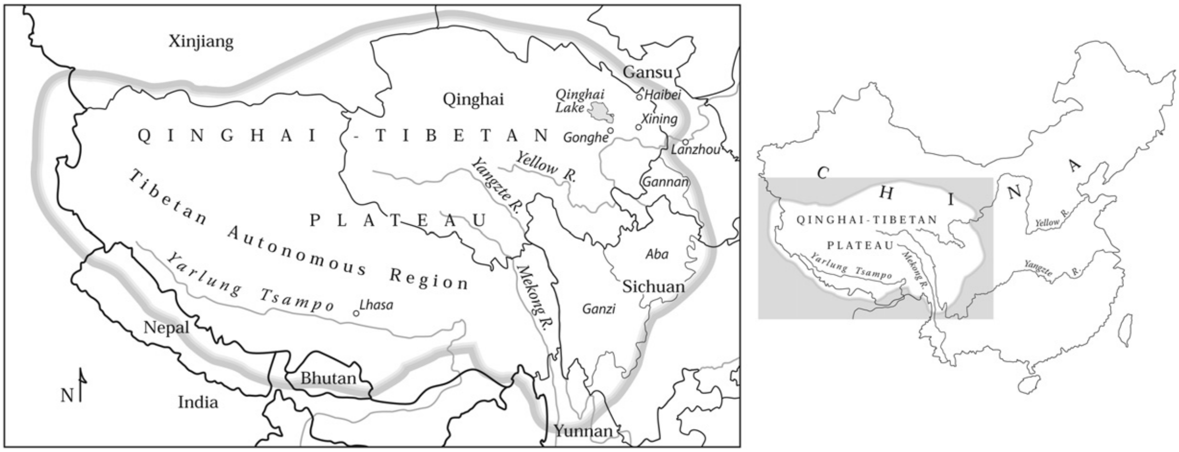

Fig. 1. The Qinghai-Tibetan Plateau (QTP) in the People's Republic of China and adjacent countries (irregular shaded line). Shown are the major rivers draining the QTP, international boundaries, provincial boundaries, and names of places mentioned in the text. Inset: Location of the QTP within China.

excessive herbivory and soil disturbance from small mammals (Li, 1994; Li and Huang, 1995; Chen, 1996; Wang and Zheng, 1999; Hou and Shi, 2002; Deng and Liang, 2003; Zhou et al., 2003; Shen et al., 2004; Zhang et al., 2004). In contrast, Western (and some Chinese) investigators have tended to question the assumption of wide-scale rangeland degradation on the QTP, and where they agree it has occurred, to cast their analysis in terms of rapid changes in socio-economic systems and alteration of land tenure arrangements (Goldstein et al., 1990; Miller et al., 1992; Miller, 1999, 2002, 2005; Williams, 1996, 1997, 2002; Ho, 1998, 2000; Foggin, 2000; Banks, 2001, 2003; Banks et al., 2003; Holzner and Kreichbaum, 2001). Because most pastoralists are Tibetan, Mongolian, or other non-Han ethnic minorities whereas political authority rests largely in the hands of Han Chinese, and because discussion of ethnic tension remains a sensitive issue in China, dispassionate analysis of rangeland degradation has been constrained by its close association with politically charged issues.

Chinese researchers (e.g., Luosan, 1996; Gu, 2000b; Ling, 2000) have emphasized technological solutions within the ecological domain. Suggested remedies for reducing overgrazing involve concentrating livestock in places where they can be protected from the elements and provided forage grown off-site, increased fencing to facilitate rotation of pastures, restructuring herds to increase the proportion of reproductive females, and manipulating herd size frequently to reflect seasonal rhythms of vegetation biomass and nutrient levels (Lobsang, 1998; Zhao et al., 2000). Suggested remedies for rehabilitating degraded rangelands invariably involve killing small mammals, temporary or permanent removal of livestock, fertilization, and/or re-seeding (Zhao and Zhou, 2005; Wang et al., 2006b).

Recent Chinese policy has followed 3 sometime conflicting approaches: (1) small mammal (usually termed "rodents") eradication; (2) subsidizing transition from semi-nomadic herding over large spatial scales to household-level ranching on much smaller spatial scales; and (3) subsidizing (or even coercing) pastoralists to sell their herds and abandon livestock raising entirely. Begun as early as the mid 1950s, efforts to poison small mammals such as the plateau pika (*Ochotona curzoniae*, not a rodent at all, but rather a member of the rabbit family, Lagomorpha) have ebbed and flowed with funding and interest and achieved variable results. By 1990, a cumulative total of 208,000 km^2 had been subject to such poisoning, usually carried out by county level agricultural, grazing, or forestry bureaus (Fan et al., 1999). Despite conclusions of most scientists that high densities of pikas were more likely a result than a cause of grassland degradation (Smith and Foggin, 1999; Smith et al., 2006), poisoning campaigns have continued, most recently in late 2006 and early 2007, when extensive efforts were expended to spread Botulinin C toxin over ~320,000 km^2 of the QTP.

Although given differing names, a number of programs share the goals of sedentarizing pastoralists and encouraging responsible rangeland husbandry by clarifying tenure of pasture land tenure on a family basis, subsidizing construction of permanent winter homes, fences and livestock shelters, and providing plots for growing supplemental winter fodder. Government outlays for these programs (often termed the "set of four" (Wu and Yan, 2002)) have been substantial; during 2003–2006, the central government reported investing some ¥7.1 billion (~$1 billion) for fencing alone (SEPA, 2007). Despite the enthusiasm with which they have been promoted by government sources, the long-term ecological and economic viability of these programs remains uncertain (Miller, 2002; Wu and Yan, 2002; Yan et al., 2005; Richard et al., 2006; Davidson et al., 2008).

In contrast, newer initiatives ("retire livestock, restore pastures") make no attempt to encourage responsible husbandry through a tighter linking of families with specific tracts of land; instead, they strive to break that linkage entirely. Under the theory that only complete elimination of livestock (for periods of 5, 10, or an undefined number of years) can restore rangeland productivity (but see Gao et al., 2007a, b for a contrary view), pastoralists have been provided free housing in township and county seats and modest 10-year living subsidies in exchange for selling their herds and ceasing pastoralism (Qinghai Province, 2003; Li, 2004; Yeh, 2005; Perrement, 2006). No training or alternative livelihoods have been reported being provided to such displaced pastoralists. In 2005 alone, the central government invested some ¥1.8 billion (~$226 billion) in this program (SEPA, 2006). However, even if the "retire livestock, restore pastures" program succeeds in reducing rangeland degradation (which itself is open to question, given that most rangeland species are adapted to some level of herbivory), it is likely to carry enormous financial burdens and create considerable social and cultural dislocation. Although implementation may encounter obstacles (Levine, 1995; Clarke, 1995; Nyima, 2003; Yan et al., 2000; Yeh, 2003), its high costs in monetary, social, and cultural terms may disqualify it from constituting a sustainable social-economic system (sensu Walker et al., 2006).

2. Extent and magnitude of degradation on the QTP

Estimates of the area variously categorized as degraded throughout China generally and on the QTP specifically have been published (Wang, 1993; Gu, 2000a; Berry, 2003; Hu and Zhang, 2003; Wang et al., 2004; Han et al., 2008), but rarely subjected to scrutiny or scientific peer review. The State Environmental Protection Agency (SEPA) estimated that one-third of China's grasslands were degraded in 1999 (SEPA, 1999), yet shortly afterward, the figure that 90% of China's grasslands were degraded became frequently cited (State Council, 2002; Deng, 2005; Li et al., 2008c).

Critically however, these nationwide statistics on rangeland degradation derive from undocumented surveys conducted by local-level staff of grassland and livestock bureaus, using criteria originally envisioned for the allocation of pasture land following de-collectivization (Northern Grassland Resource Survey Office, 1981). These criteria required that all grassland be categorized as non-degraded, or lightly, moderately, or heavily degraded. Standards and methods for such classification were subjective, with only a single quantitative measure (reduction of vegetation production of 20–30% for light, 20–50% for moderate, and >50% for heavy degradation; Lu, 2002; Zhang et al., 2004). However, even this quantification was murky, because neither a baseline from which to assess reduction, nor field methods to use in measuring it were provided (although Zhou et al., 2005a provided a useful description of vegetative correlates of each category). Because almost any grazing reduces standing biomass relative to an ungrazed condition, the mere presence of livestock in an area may have precluded it from being categorized as "non-degraded".

Required to produce such classification over enormous areas, and provided with few staff and little training, local grassland bureaus almost certainly classified areas under their jurisdiction based on superficial and subjective impressions. Thus, attempts sometimes made to use degradation statistics in further analyses (e.g., Liu et al., 1999a; Wang and Cheng, 2001; Ma et al., 2004; Li et al., 2006) or higher-order models (e.g., Deng, 2005) have been built on a weak foundation.

Attempts to quantify the extent of rangeland degradation more rigorously than provincial surveys (if on a more limited geographic scale) have yielded conflicting results. Satellite imagery in southern Qinghai failed to support Chinese scientists' claims of range degradation during the 1980s and 1990s (Perryman, 2001). Goldstein and Beall (2002) found no evidence of degradation claimed by local officials in the western Tibet Autonomous Region (TAR) where they worked. Holzner and Kreichbaum (2000) estimated 30% of TAR rangelands to be in an optimal state. Conversely, Bedunah and Harris (2002) found evidence of substantial rangeland degradation in a western section of the Qilian Shan despite recent reductions in livestock numbers and the fact that local government statistics suggested that pastures were below carrying capacity.

As of 2005, there were an estimated 30 million sheep (including goats) and 12 million yaks on the QTP (Miller, 2005). Increases in livestock numbers since 1949 – some gradual, some quite dramatic – have been published (Cincotta et al., 1992; Sheehy, 2001; Bai et al., 2002; Deng and Liang, 2003; Hu and Zhang, 2003; Zhang et al., 2004; Zhao and Zhou, 2005). However, reports disagree on the timing of increases in livestock number, with some suggesting peaks in the 1980s and other suggesting continued increases since that time (Perryman, 2001; Harris and Bedunah, 2001; Bai et al., 2002; Bedunah and Harris, 2002; Goldstein and Beall, 2002; Zhou et al., 2005a). Further, temporal dynamics of livestock numbers do not always accord with the dynamics of the rangeland conditions they have purportedly caused, even assuming some lag effect.

In any case, analyses based on official livestock statistics should be viewed with great caution. Because they have a history of being manipulated at both local (usually under-reported by pastoralists (Yan et al., 2000), often with the tacit approval of local officials) and higher government levels (possibly over-reported, in the belief that higher numbers indicated economic progress and meeting development milestones or quotas), livestock numbers cannot necessarily be assumed to be accurate or even representative. In particular, livestock numbers reported during the early years of the People's Republic may be misleading (Goldstein and Beall, 2002).

Chinese scientists have produced convincing evidence that some QTP rangelands are sensitive to high livestock densities. Experiments using controlled stocking rates in small paddocks at the Chinese Academy of Science's Haibei Research Station (at a relatively low elevation of ~3200 m) showed that standing biomass declined with increasing grazing intensity (Wang et al., 1995). Trends in species composition were also associated with stocking rates, notably a reduction in the relative abundance of palatable grasses and a corresponding increase in forbs and poisonous plants (Zhao et al., 1988; Han et al., 1991; Zhou et al., 1995b; Zhou et al., 2002). A longer-term study suggested that grazing intensity had little effect on overall vegetation cover or species richness, but that palatable grasses (largely *Stipa* spp.) were progressively replaced by forbs (e.g., *Leontopodium* spp.) with heavy grazing (Zhou et al., 2004). Tellingly, animal weights, at least in selected areas, are reported to have declined considerably from the 1960s to the 1990s (Zhou, 2001).

In contrast, other studies found that *Kobresia humilis*, one of the most important forage plants in some parts of the QTP, showed no evident reduction in overall biomass with increased stocking density (Zhu et al., 1994), or a decrease only at the highest stocking levels (Li et al., 2001). Studies by Gao et al. (2007a, b) showed higher soil nutrients in moderately grazed pastures than either heavily or lightly grazed pastures.

3. Hypotheses of rangeland degradation on QTP

Before assessing the wisdom of strategies to safeguard or rehabilitate existing rangelands one must first understand the causes of rangeland degradation. Many analyses of this question rely on logical shortcuts, selective inclusion of existing data, and/or underlying prejudices. Although it is likely that there is no single cause, the presence of multiple, interacting factors does not preclude dispassionate and skeptical analysis of each. Simply listing a number of possible (or even probable) causative agents, as many assessments have, does little to move knowledge forward. Citing "climate change" without specifying or documenting mechanisms linking highly complex climate phenomena with equally complex biotic phenomena obscures as much as it illuminates. Lumping grassland reclamation projects undertaken in the late 1950s together with high livestock densities managed by Tibetan herders in the 1990s as undifferentiated "human factors" within a single, omnibus menu of degradation causes does little to advance understanding (it's unlikely that immigrants attempting biologically implausible agriculture on the QTP during the Great Leap Forward were responding to similar economic or political incentives as were early 21st century Tibetan herders overgrazing their pastures with an eye toward the prices offered by livestock traders arriving from Xinjiang, even if the activities of both resulted in some sort of rangeland degradation).

Here, I examine claims made in the literature for the causal agents of recent degradation on QTP rangelands, recasting each as a hypothesis. In some cases, I've interpreted and rephrased various claims put forward, grouping and abstracting them. For each hypothesis, I ask whether there is empirical evidence to support the existence of the phenomenon in question (i.e., is it really happening?) and whether there is evidence or logic supporting the phenomenon's role as a cause of rangeland degradation (i.e., does it make sense as a contributor). In assessing each, I have supplemented published literature with my own observations, obtained during some 20 years in various rangeland types within northern portions of the QTP (Harris, 2007).

I have identified 7 putative drivers of rangeland degradation on the QTP suggested by published and unpublished literature in either Chinese or English (two of which I subdivide, producing a total of 12 hypotheses), which are ascribed differing credibility and weight by each author. These causes are rarely mentioned in isolation, but I've separated and numbered each here for purposes of clarity (Table 1). In some cases I was unable to characterize a claim made by an author because it was too vague. For example, many authors referred to "overgrazing" or "overstocking" but without time period or socio-economic association (e.g. Li et al., 2003a; Wang et al., 2008b), making it difficult to recognize this as a putative cause.

3.1. *Inherently harsh climate and fragile soils*

Some Chinese authors have cast the harsh nature of the QTP, with its limited primary productivity and fragile soils, as a cause of its own degradation (e.g., Li et al., 2003a; Zhang et al., 2004), as if this were some newly emerging limitation rather than a well-known characteristic that has for millennia molded native flora and fauna as well as human adaptations to them. In characterizing the QTP as a difficult place for plants and animals to make a living, such scholars are undoubtedly correct. However, the question to ask is not whether vegetation types and primary productivity are intrinsically limited in such an environment, but rather whether vegetation has changed and/or productivity decreased in recent decades. That climate and soils differ from those in more temperate regions of the world is beyond dispute, but I know of no evidence that intrinsic biological conditions have worsened in recent times. Thus, the simple fact that life is tough on the QTP cannot logically be invoked as a cause for rangeland degradation.

3.2. *Global climate change*

3.2.1. *Reduced precipitation*

A number of Chinese sources claim the QTP has experienced a general drying trend in recent decades, negatively affecting rangelands (Luosan, 1996; Yan, 2001; Li et al., 2003b; Yang et al., 2004a; Ye and Dai, 2004; Zhang et al., 2004; Deng, 2005; Zhou et al., 2005a). But data generally provide no evidence of reduced precipitation on the QTP over this time period. In most cases, weather records show no discernible change in precipitation amounts over the past few decades; in the few places where changes appear to have occurred, weather records suggest a trend toward a wetter climate, not a drier one (reviewed in Harris, 2007).

Table 1
Putative causes of rangeland degradation on the Qinghai-Tibetan plateau (QTP), as abstracted from published and unpublished sources.

Putative cause of rangeland degradation	Strength of evidence
1. The QTP is a harsh and cold environment characterized by fragile soils	Logic lacking
2a. A desiccation trend on the QTP via reduced precipitation, leading to reduced production	Only in isolated areas
2b. A warming trend on the QTP has led to reduced or altered production	Generally weak
2c. Receding glaciers have led to rangeland degradation	Logic lacking
2d. Reduction in depth and extent of permafrost has led to rangeland gradation	Persuasive in some areas
3. Small mammals destroy rangelands	Generally weak
4. Unsustainable conversion of rangelands to cultivated crops	Persuasive in limited areas
5. "Backward" livestock husbandry practices	Too poorly articulated to assess
6. Privatization and sedentarization (including fencing)	Persuasive in some areas
7a. Overstocking resulting from livestock being valued as wealth	Generally weak
7b. Overstocking resulting from population increase of pastoralists	Logically plausible but poorly documented
7c. Overstocking as a rational response to current mixture of socio-economic incentives	Logically plausible but poorly documented

The most thorough, geographically complete, and analytically exhaustive analyses to date appear to be those of Domrös and Schäfer (2003), Gemmer et al. (2003), and Chen et al. (2006). The first two sources display maps of China with almost the entire west showing no significant change in annual precipitation for 1951–1999. Domrös and Schäfer (2003), while concerned about future drying (as well as warming) in China generally, concluded that although "precipitation is expected to decrease in most eastern parts… slight increases in the western parts are projected." Gemmer et al. (2003), while cautioning against over interpretation of data from western China due to small sample sizes, nevertheless showed more months with positive precipitation trends than negative trends. In a broader analysis, Hulme et al. (1994) concluded that data show "a weak tendency for increasing annual precipitation over the last 100 years" in East Asia as a whole, and that while "much of southern and eastern China has experienced reduced annual precipitation… Northwest China has seen a slight increase in precipitation."

For the Gansu corridor, Chen et al. (2002) presented precipitation trends from twenty-two meteorological stations, none of which displayed statistically significant declines from the early 1950s to 1999, although three stations (Sunan, Qilian, Gaotai) had significantly positive trends of precipitation on time. For the QTP, Gao (1995) showed no significant trend for precipitation at Wudaoliang. Piao and Fang (2002), based on 670 weather stations displayed a positive precipitation trend for all of Qinghai and the TAR during 1982–1999. Du et al. (2004) similarly showed a non-significant, positive trend in precipitation for the TAR. Chen et al. (2006) evaluated trends of potential evapotranspiration (PET) throughout the QTP over the past four decades. Overall trends were negative (suggesting that conditions were generally becoming less dry), particularly during spring. Zhang et al. (2007) also reported positive precipitation trends and negative PET trends in 6 areas of the northern TAR during 1981–2000. Zhang and Welker (1996) had earlier conducted small-scale field experiments at the Haibei Experiment Station in Qinghai suggesting that environmental conditions similar to those leading to the lower PET documented by Chen et al. (2006) increased the production and growth period of alpine grasses. I conclude that there currently is no persuasive evidence that recent global climate change has led to reduced precipitation generally on the QTP.

With a few exceptions, reliable weather recording has only taken place in western China since the early 1950s, so another possibility to examine is that, while there has been no general drying trend during the past half-century or so, these years themselves have been, on the whole, dryer than average on the scale of a few centuries.

Although it is clear that the environment on the QTP was wetter about 8000 years ago than in recent times (Gasse et al., 1996) – and even wetter than that some 30–40,000 years BP (Shi et al., 2001; Yang et al., 2004a) – tree-ring analyses from sites around the QTP suggest no drying trend within the past 400–600 years. If anything, recent times have been wetter than the average climate during the past few centuries (Wang et al., 1982; Kang et al., 1997; Zhang and Wu, 1997; Qin et al., 2003; Bräuning and Mantwill, 2004; Sheppard et al., 2004; Li et al., 2008a; although see Liu et al., 2008 for a counter-example at a relatively low elevation site on the eastern fringe of the QTP).

3.2.2. Climate warming causing desiccation

There is general agreement that the QTP is particularly sensitive to global climate change (Cheng and Wu, 2007; Wang et al., 2007). Sources providing statistical evidence of a general warming trend in western China over the past five decades include Hulme et al. (1994), Liu and Chen (2000), Shen and Varis (2001), Domrös and Schäfer (2003), Gemmer et al. (2003), Yu et al. (2003), Du et al. (2004), Qian and Lin (2004), and Wu and Liu (2004) (although Frauenfeld et al., 2005 suggested that warming reported on the QTP has been biased by the low elevation and proximity to urban areas or those subject to recent land-use changes of most weather stations). Further, the same tree-ring analyses that provided no evidence for reduced precipitation in recent centuries do suggest substantial warming.

However, whether or not desiccation related to warming itself is a plausible cause of rangeland degradation, as claimed by some (e.g., Li et al., 2003a; Zhou et al., 2003) is not clear. In assessing the possible effects of this warming on vegetation, one must consider the seasonality of the trends (because vegetation is differentially affected by temperatures during various growth stages, and is least affected when it is dormant in winter). On the QTP, the majority of mean annual warming has been caused not by hotter summers but by milder winters. For example, Liu and Chen (2000) estimated warming rates of 0.016 °C/year for annual means but 0.032 °C/year for winter means using 97 stations distributed over the entire QTP during 1955–1996. Du et al. (2004) reported an annual warming trend of 0.02 °C/year in summer but 0.13 °C/year in winter for Qinghai and Tibet, 1978–1999. Domrös and Schäfer (2003) concluded that "in winter, increasing trends prevail; strongest increases (greater than 1.5 °C) can be observed in northwestern and northeastern parts of China," whereas, "[in] spring and summer no uniform trend can be observed…." Shen and Varis (2001: 382) concluded, "Winters have become distinctly warmer whereas summers either cooled or became slightly warmer." Frauenfeld et al. (2005) also showed most warming as occurring in non-growing seasons. In contrast, local data showing summer as well as winter warming for Deqin, Yunnan, at the southeastern extreme of the QTP, were presented by Baker and Moseley (2007).

It is worth considering what effect the relatively small increase in summer temperatures would have on vegetation growth on the QTP where growing seasons are short and cold to begin with. Is such a warming likely to exacerbate desiccation or promote more vigorous growth? On the QTP, it is possible that warming may enhance grassland growth. Du et al. (2004) speculated that "climate warming may promote vegetation growth on the Tibetan Plateau." Piao and Fang (2002) and Piao et al. (2004, 2006) based on remote sensing data during the period 1982–1999, documented an increase of roughly 1 percent annually in net primary productivity as averaged over all of Qinghai and the TAR. Xu and Liu (2007) similarly interpreted increases in Normalized Difference Vegetation Index (NDVI, a surrogate for biomass and productivity) on the QTP during 1982–2002 as resulting from recent warming. Chu et al. (2007) found a positive trend in NDVI during 1985–1999 near Lhasa, whereas Zhang et al. (2007) found inconsistent relationships between mean temperature and NDVI in the northern TAR. Zhang and Welker (1996) had earlier found that grasses responded positively to artificial warming.

In contrast, Klein et al. (2004) demonstrated that losses in vegetation species richness would likely accompany warming, although losses were reduced in the presence of simulated grazing (i.e., clipping). Klein et al. (2007) also reported a decline in above ground net-productivity, particularly of palatable grass species, under mean warming of 1.0–2.0 °C during the growing season. Thus, if global warming increases summer temperatures, in addition to winter temperatures as has been primarily reported thus far, it could result in reduced rangeland productivity of QTP. In addition, climate-vegetation dynamics may also be complex: reductions in vegetation cover may induce warming and drying rather than vice versa (Holzner and Kreichbaum, 2001; Du et al., 2004).

3.2.3. Receding glaciers

As with the warming trend, there is little dispute that glaciers on the QTP are in general decline as a result of recent climate change (Rikiishi and Nakasato, 2006; Baker and Moseley, 2007; Pu et al., 2007; Yao et al., 2007; Li et al., 2008b; Xin et al., 2008; Yang et al., 2008). However, some authors (e.g., Shang and Long, 2005) have listed glacial retreat as among direct causes of grassland degradation (in particular, the increase in "black beach", highly eroded areas in high-elevation, *Kobresia*-dominated meadows). Although retreating glaciers will obviously have impacts on hydrology (particularly for downstream water users), it is unclear how loss of glaciers per se would affect rangeland conditions, nor has such a direct mechanism been suggested by these papers. It seems likely that naming receding glaciers as a cause of vegetation degradation is actually an attempt to support the claims of other climate-related hypotheses.

3.2.4. Reduced depth or extent of permafrost

Alterations in the extent and depth of permafrost, which is also known to have occurred on the QTP (Wang, 1993, 1997; Jin et al., 2000; Wang et al., 2000; Lin et al., 2004; Wu et al., 2006) may be related to changes in rangeland productivity (Li and Huang, 1995; Li et al., 2005; Oelke and Zhang, 2007; Zhang, 2007). The active layer, which is subject to repeated freezing and thawing, is more vulnerable to weathering and subsequent reductions of vegetation than is the permanently frozen layer (Yang et al., 2004b; Zhao et al., 2004; Li et al., 2008b; Wang et al., 2008a). Thus expansion of the depth or extent of the active layer could lead to erosion and loss of productivity, and has been implicated as a factor in retreating lakes and wetlands (Wang et al., 2006a; Cheng and Wu, 2007; Zhang, 2007).

Data collected and models constructed thus far suggest that such effects should be observed mostly in the highest, coldest sedge-dominated meadows (typically pastoral summer ranges; Wang et al., 2006a), where "black beach", a condition in which the entire turf layer sloughs off revealing bare mineral soil, has been the subject of considerable restoration efforts. Overgrazing and burrowing by small mammals are usually blamed for black beach, but it has also been observed where grazing is light and small mammals uncommon, suggesting a climatic contribution (D. Miller, USAID, New Delhi, India, personal communication, 2008).

However, grassland degradation has occurred on lower elevation winter ranges in addition to typically high-elevation summer ranges (including areas without permafrost (Jin et al., 2000; Li et al., 2008b)). Additionally, interpreting correlations between loss of permafrost and grassland degradation is not straight-forward, because causation may run in either direction. Although changes in the dynamics of water and nutrient retention resulting from loss of permafrost likely affect vegetative composition and productivity, loss of vegetative cover (whose causes, presumably, lie elsewhere) may also be a factor in promoting or accelerating permafrost loss (Wang, 1993; Wang et al., 2008a). Yang et al. (2004b) postulated dynamics in which human-caused loss of vegetative cover led to permafrost degradation, which in turn, further exacerbated the trend of vegetation loss.

Still, the claim that permafrost loss caused by global temperature increases can induce substantial changes in hydrological dynamics and thus in vegetation is logical. At least one study has suggested that the depth of seasonally frozen soil in areas devoid of permafrost was positively correlated with vegetative biomass (Li et al., 2005).

Thus, it may yet emerge that loss of permafrost or thinning of seasonally-frozen soil caused by warming has been a substantial contributor to rangeland degradation, at least locally, but additional site-specific and hypothesis-driven research is needed.

3.3. Damage by "rodents"

Plateau pikas are known to be important ecosystem engineers and have disproportionate effects on biodiversity on the QTP (Smith and Foggin, 1999; Lai and Smith, 2003; Zhang et al., 2003). Early Chinese work simply blamed plateau pikas for grassland degradation (e.g., Liu et al., 1980), based on the fact that they consume vegetation and create burrows in the soil. However, researchers in Qinghai have increasingly interpreted high pika abundance as resulting from, rather than causing degraded grasslands (Shi, 1983; Liu et al., 1991; Bian et al., 1999; Fan et al., 1999; Liu et al., 1999b; Zhou et al., 2005b). (Some authors – despite lacking evidence – have blamed reductions of natural predators for high pika densities, e.g., Li et al., 2003a). Pech et al. (2007) documented density-dependent increases in pika abundance following control.

There now seems a consensus that pikas, as well as burrowing or fossorial rodents such as Plateau zokors (*Myospalax baileyi*), voles (*Microtus* spp.), and jerboas (*Allactaga* spp.) are naturally-occurring features of healthy rangelands on the QTP. Pikas evidently remain at moderate densities when vegetation cover is high, but can increase to high densities in response to vegetation loss (probably because survival is enhanced when they can easily detect avian predators). At these high densities, pikas themselves exert a negative force on trophic dynamics, encouraging the continuation of a degraded state. Thus, while definitive studies disentangling cause and effect have yet to be conducted, it seems likely that pikas (and other "rodents") are at most a cause of exacerbating rangeland degradation whose origin lies elsewhere, and probably more accurately, seen as an indicator than a cause of rangeland degradation on the QTP.

3.4. Unsustainable conversion of rangelands to cultivated crops

Attempts to cultivate land for crops that are suited only for pastoralism are generally agreed to lead to rangeland degradation, both because of direct effects on vegetation, soils, and hydrology, and indirect effects of concentrating an unchanged number of livestock on a smaller land base. However, according to statistics complied by Deng (2005, p. 154), cultivated areas on the QTP currently constitute less than 0.5% of the region's natural grasslands, and about half that proportion of the total landscape. Most highland agriculture is concentrated around Qinghai Lake and surrounding basin areas, where elevations are typically only slightly above 3000 m. Substantial agricultural acreage is also found in Aba and Ganzi Prefectures of Sichuan, but aside from these areas, very little agriculture currently take places in the core pastoral areas of the TAR and southern Qinghai, and where it does, it is located mainly in the valley bottoms where it has been practiced for centuries.

However, Deng (2005, p. 160) also points out that, while on a relative scale the acreages were modest, government-sponsored programs of "reclaiming wasteland" for crops were particularly active during or just after the Great Leap Forward, and, to a lesser degree, continued throughout the collective era. Most of the areas affected were evidently in Qinghai Province, with others in Hongyuan, Sichuan and Gannan, Gansu. Further, most of these lands were later abandoned, and it is likely that soil erosion and nutrient loss prevented them from recovering to become productive grasslands later. Many areas "reclaimed" were on winter pastures, and may have been among the most valuable for livestock. Rangelands in some areas, for example in the Gonghe Basin in Qinghai's Hainan Prefecture, have evidently continued to suffer from ambitious agricultural expansion (Deng, 2005, p. 173, see also Zeng et al., 2003, although these latter authors make no mention of historic reclamation), even after the follies of earlier policies were recognized. Wang et al. (2008b) also identified recent cultivation as a contributor to grassland degradation in nearby Gannan Prefecture in Gansu, and Wang et al. (2008c) identified economic forces as continuing to favor cultivation over grazing in Dulan County, Qinghai. On a local scale, these (mostly) historic activities have no doubt contributed to rangeland degradation, whether recognized at the time or only much later.

Still, it is unclear how much these relatively local areas of historic misuse have contributed to statistics suggesting degradation over larger areas. If they are important contributors, they may be skewing averages in a way that tar purely pastoral areas with the same brush that paints these areas so darkly. If not, they may simply be anomalies, locally consequential but not globally important drivers of rangeland degradation on the QTP.

3.5. "Backward" pastoral production systems

A number of Chinese papers list "traditional" or "backward" practices on the part of pastoralists as a cause of degradation, without specifying which practices they mean (e.g., Zhou et al., 2003; Zhang, 2004; Zhou et al., 2005a). In some cases, irrational herd structures are identified as leading to unnecessarily high livestock densities (e.g., Zhou, 2001). In other cases, subsistence (as opposed to market-based) pastoralism is sometimes identified as a cause of degradation in its own right (Zhang, 2004). In often denigrating traditional pastoral systems, the assumption is usually made that higher production of livestock products is a goal (although Wu and Du, 2007 criticized Chinese researchers' focus on productivity at the expense of concern about biodiversity). Chinese research has emphasized theoretical optimization of herd size and structure and the need for external inputs (e.g., fertilizing, seeding, haying), but has generally paid little attention to the ecological, economic or social sustainability of proposed livestock management systems (Gu, 2000b; Zhao et al., 2000; Zhang, 2004).

It seems beyond dispute that prior to adopting some of the initiatives of the "set of four" policy, pastoral practices used by Tibetans and other pastoral groups on the QTP were traditional, largely unchanged from those used for centuries. Even now, after the partial sedentarization that many have adopted (e.g., living in houses rather than tents, fencing winter areas, using concrete warming sheds during spring lambing), livestock husbandry on the QTP is quite different from that in industrialized economies. It is also true that herd structures (e.g., male: female ratio) are often not those designed for maximum offtake.

But authors invoking "backwardness" are generally concerned about conditions on QTP rangelands that are considered to be rather recent in origin. If lack of technology or a scientific approach to animal husbandry per se is problematic, a logical corollary should be that the degraded conditions of concern now have existed for as long as pastoralism has been the dominant land use (unless pastoralists have somehow become more backward or less scientific in recent decades). To the degree that a subsistence economy is itself a problem, rangeland trends should have started trending positively a few decades ago because pastoralists on the QTP have increasingly become embedded in larger market economies; truly subsistence pastoralism has declined steadily since the founding of the PRC. Indeed, if trends away from palatable perennials and toward desertification are no greater now than in the past, one needs to ask why the system didn't collapse long ago.

In casting doubt over the simplistic assertion that traditional semi-nomadic pastoralism has itself degraded QTP rangelands, I don't intend to imply that it is necessarily ecologically sustainable under any or all conditions (i.e., that it cannot lead to degradation). As with any cultural-economic system, it may be sustainable under certain external circumstances and not under others. But it does appear logical that the mere fact that most rangelands of concern are considered to have been in much better condition only a few decades ago is sufficient to conclude that traditional pastoral systems can be consistent with long-term sustainability, and thus cannot, of themselves, be identified as a cause of degradation.

3.6. Privatization and/or sedentarization (including fencing)

Research by most Western-based observers has focused on assumed sustainability and resilience of traditional herding systems that used large-scale movements to mediate short-term livestock-pasture imbalances (Goldstein et al., 1990; Miller et al., 1992; Miller, 1999, 2002; Foggin, 2000; Banks, 2001, 2003; Banks et al., 2003). Most of these authors have paid less attention to desires pastoralists may have for the better access to schools or medical care that Chinese policymakers claim will come with a household-scale ranching model (Zhao et al., 2000; Yu, 2003; Zhang, 2004; Lu and Lu, 2004). These Western authors have focused primarily on the social, cultural and economic effects of sedentarization. Although limiting flexibility to exploit distant pastures may cause starvation among livestock (and hardship for pastoralists) during years of drought or snowstorms, this would not necessarily lead directly to overstocking or rangeland degradation.

Concentrating livestock near settlements does seem likely to negatively affect vegetation locally; indeed, one need only visit winter houses – now used for increasingly lengthy periods – to observe how vegetation is adversely affected by constant use and trampling. Fences used to protect pastures from seasonal use or trespassing livestock often have the effect of increasing the intensity of use surrounding them. Thus, it stands to reason that a less mobile herding strategy, absent any other changes, is more likely to intensify pressures on rangelands than to ameliorate them. (Of course, the objective of such policies did not envision sedentarization as an endpoint, but rather as a means to more clearly demarcate natural limits, and thus as an incentive to limiting herd size).

But even here, empirical evidence showing that sedentarization policies have exacerbated rangeland degradation (in contrast to their nominal justification) is scant. Monitoring rangeland trends in a way that could provide feedback on the biological effects of sedentarization programs has simply been insufficient (or too poorly documented and published) to allow a clear picture.

3.7. Overstocking

3.7.1. Livestock numbers themselves are considered the best measure of wealth

Among some Chinese authors, an often assumed – although infrequently articulated or examined – characteristic of traditional pastoralists is that livestock as viewed as synonymous with wealth (Miller, 2005 points out that the Tibetan term for yak, nor, can also be translated as "wealth"). Therefore, the logic continues, pastoralists attempt to maximize livestock numbers, even at the expense of rangelands and soils. Bai et al. (2002) considered that Tibetans' valuing of livestock as wealth regardless of their effects on vegetation was the primary cause of the tremendous increase in livestock numbers in Maduo county, Qinghai during the 1960–1980 period (roughly a quadrupling of numbers in two decades' time). But Bai et al. (2002) failed to ask why, if Tibetans' consistently valued high numbers of livestock, animals were so few in 1960, or why herds plummeted again after 1980. Rather, the simple assertion was made that the increase was because of irrational Tibetan values, and the decline was because of rangeland limitations. Might there have been other factors at work? The question wasn't asked.

Simpson et al. (1994, p. 79) also accepted the notion that pastoralists tend to prefer large herds, but rather than leaving it at that, brought it into economic context: "It is true that producer preference in pastoral areas for ownership of large numbers of livestock seems to be a root problem of low offtake rates and overgrazing. But… this attitude is no more irrational than an urban resident obtaining esteem by ownership of material goods such as a motorcycle or a new television set. Ownership of large numbers of animals is a rational production risk avoidance mechanism… at the root are poor transportation systems and vast distances that simply result in very low prices to producers in remote areas." Others who have investigated traditional pastoral practices have also noted that high livestock numbers were often seen as a hedge against density-independent declines, allowing a better chance for herd re-establishment following a drought or blizzard that would kill a large proportion of any sized herd (Goldstein et al., 1990; Wu and Yan, 2002; Miller, 2005).

I am not aware of rigorous surveys of Tibetan, Mongol, or Kazak pastoralists that could shed light on whether or not a culturally-embedded preference for high livestock densities typically trumps other considerations. My own experience supports the literature in suggesting that pastoralists with many livestock consider themselves better off than those with fewer. But it does not necessarily follow that livestock per se make them wealthier; it seems just as plausible that higher numbers of livestock result from wealth as that they are wealth. To the degree that pastoralists operate in the cash economy, it seems equally plausible that higher numbers of livestock simply allow for higher sales, allowing more flexibility in how wealth is stored. Thus, while a cultural desire for high livestock densities may exist, it seems far from demonstrated that it necessarily leads to overstocking and/or to rangeland degradation.

3.7.2. Population growth among pastoralists

Some authors have identified simple population growth among pastoralists as causing overstocking and thus rangeland degradation (e.g., Zhang et al., 2004; Li et al., 2008c). It is beyond dispute that, subject to less stringent birth-control measures than urban residents (if any at all), population growth rates among pastoralists on the QTP have far exceeded those within China generally. Data in Riley (2004) suggests the growth rate of Tibetans and Kazaks during 1982–2000 was about double that of Han; see also Fischer (2008). Deng (2005) compiled provincial records to estimate a mean population density within pastoral areas of the QTP as about 2.5/km^2 in 2000, although even this figure may be an overestimate if it averages county centers together with purely pastoral areas (Foggin et al., 2006). Estimating the rate of increase among pastoralists is complicated, however, by methodological issues and the selection of time periods (Fischer, 2008).

That said, if – as seems logical – the number of livestock (or amount of wealth they can create indirectly) must remain at a similar per capita level to maintain an unchanging living standard, it seems plausible that simple population growth could lead to chronic overstocking, even if the system were sustainable at lower human population densities. Again however, empirical data linking higher livestock densities causally to the number of pastoralists is surprisingly sparse. Zhang et al. (2007), using remote sensing in the northern portion of the TAR, concluded that in 2 of 6 counties studied, vegetation biomass production, as measured by NDVI, was negatively correlated with human population during 1981–2001. However, correlations in 4 other counties were not significant (and 2 were positive). Thus, if local population increases had led to livestock increases that in turn led to reductions in NDVI, the effect was, at best, inconsistent.

A study implicating pastoral population growth as causative would need to be carefully designed to exclude the many other competing hypotheses. Simple correlation, as much Chinese work has employed, will almost certainly lead to conclusions that are seriously confounded because so many other factors have changed contemporaneously with the number of pastoralists.

3.7.3. Short-term economic benefits overwhelm long-term interests

The final hypothesis I consider has rarely been articulated directly in the literature, although a few authors (e.g., Shen et al., 2004; Zhang et al., 2004) have hinted at it. It may be so obvious and intuitive that none thought articulating it necessary. If so, I would differ: clarity in identifying our hypotheses can only help in determining what is happening.

Briefly, this hypothesis is that nomadic pastoralists are not unlike most others in responding to the combination of economic and political incentives: they tend to choose the path they perceive will bring the most benefit and least pain to themselves and their families. Prior to imposition of state control, this meant a traditional semi-nomadic pastoral lifestyle, in which herd sizes were limited by a combination of natural factors and the needs of their largely-subsistence lifestyle. During the collectivization period, when immediate livestock production requiring large numbers of animals was evidently mandated by policy, they increased their herd sizes (perhaps to beyond what could be sustained). Shen et al. (2004) suggested that government policies during the Great Leap encouraged high livestock densities; Zhang et al. (2004) cited the Cultural Revolution period as the beginning of unsustainably high livestock densities in southern Qinghai. It is difficult to know if these dynamics were more general, because the authors of Shen et al. and Zhang et al. are exceptions: most Chinese authors have avoided linking natural resource management with the politics of the day.

With the dissolution of collectives and the rapid transition to a market economy in the 1980s, many pastoralists modulated their herd sizes to those which they perceived would make them the most money. Cincotta et al. (1992) documented a general herd increase since decollectivization in northern Qinghai; Zhang et al. (2004) also implicated the economic reforms of the 1980s as exacerbating the trend toward high livestock numbers. With the increased prices available for sheep and goat products (largely arising from outside the local area) and the increased ease of access to distant markets (largely in the form of mobile livestock purchasers from Xinjiang, Gansu, or eastern Qinghai), larger herds meant larger profits (at least in the short term). Lack of power to negotiate higher prices meant that only by increasing herd size could they make a higher profit. Increased interaction with town life eased the ability to store wealth in ways other than pasture, thus cushioning any feedback in the form of lower livestock productivity per capita. Increased interaction with the non-pastoral sector also provided alternative visions of a better future (e.g., schooling for children) than merely the health of the pastoral allotment. Finally, lack of secure land tenure – the intentions of the 1985 Grassland Law notwithstanding – would have favored these short-term benefits over a long-term perspective of pasture sustainability. The 50-year contract most pastoralists entered into might seem sufficient to provide for a long-term perspective, but the plethora of government policies and pronouncements and uneven administration of the Grassland Law's stipulations may have conspired to undermine the psychological sense of ownership that they had intended to provide.

An assumption underlying recent Chinese policy initiatives toward quasi-privatization and market-based livestock husbandry is that feedbacks in the system will function to reward conservative, and punish excessive livestock densities. But there are reasons to doubt the assumption that feedbacks in the biological realm (e.g., declining yield/animal from overstocking) will translate into incentives in the economic realm, at least over a time horizon within which pastoralists would recognize the linkage. Studies conducted by the Chinese Academy of Sciences at Haibei, Qinghai, demonstrated negative relationships between annual weight gain of sheep and stocking density (Zhou et al., 1986; Zhou et al., 1995b; Zhou, 2001); at Dawu, Qinghai, similar studies yielded similar relationships with yaks (Dong et al., 2005). If pastoralists profit by producing heavier animals (or by growing them faster rather than slower), this dynamic could theoretically function in a market-based setting to limit stocking densities. Zhou et al. (1995a) attempted to show just this: by calculating weight gain per unit area as a function of livestock density and then fitting a logistic model to these data, they concluded – as their underlying model forced them to – that economically-optimal stocking occurred at half the theoretical carrying capacity (which likely would have exerted relatively little pressure on rangelands).

However their data on sheep weight gain/area displayed no evidence of the parabolic shape assumed by the logistic model; in fact, it showed no evidence of variation at all. Thus, rather than supporting the authors' contention that the optimal stocking rate occurred at half the carrying capacity (about 2 sheep/ha in their case), their data suggested no loss in per area productivity to a pastoralist who stocked at 3 sheep/ha or even greater densities, at least within the short time-frame of the study. Thus, contrary to the hopeful conclusions of Zhou et al. (1995a), their data seemed to suggest that pastoralists making livestock management decisions based on livestock biomass produced per unit area would rationally opt to compensate for lighter animals simply by keeping and selling more of them.

While this final hypothesis appears consistent with many patterns, it too lacks clear and convincing evidence. We don't really know why pastoralists have made the decisions they have, at least under the current mixture of political-economic incentives. Research linking incentives to rangeland condition via pastoralists as intermediaries, has not yet been conducted on the QTP.

4. Summary and research needs

I have identified 12 non-exclusive hypotheses to explain range degradation on the QTP, and attempted to examine the basis and evidence available for each (Table 1). Some appear to fail the most basic tests of logic and should be abandoned. Others seem to lack supporting evidence, and thus should be viewed skeptically. Yet others are logically plausible and can claim some support from data (or at least from anecdotal evidence). In my view however, none has been explored sufficiently rigorously to confidently assert a causal linkage.

It seems clear that Chinese policy will not tolerate a return to traditional nomadic pastoralism over large spatial scales, nor does this seem feasible given recent integration of livestock production systems on the QTP with distant markets and with on-going socio-economic development taking place in pastoral areas. Some kind of modernized livestock management, even if not what Chinese policy currently promotes, must ultimately be adopted. But even where it can be safely assumed that rangeland degradation is serious and that it has been caused by excessive livestock numbers, there has been very little rigorous Chinese research into the reasons for overgrazing and rangeland degradation. Most Chinese biological research has not asked, much less answered, questions regarding human motivations among the pastoralists using the rangelands of the QTP, but this has not kept many authors from suggesting simple reductions in livestock numbers or dramatic changes in livestock production systems (e.g., Gu, 2000b; Li et al., 2003a; Ma et al., 2004). The synthetic approach that is critical to understanding the etiology of the rangeland degradation problem and thus to proposing policies that are both ecologically, economically and socially sustainable has largely been lacking in China (for exceptions, see Wu and Yan, 2002; Yi et al., 2008). Within China, open inquiry into the problem of grassland degradation on the QTP has no doubt been constrained by its close association with sensitive issues bearing on cultural conservation and political control. However, sustainable rangeland management and economic development of the QTP will require more nuanced approaches which start with a more thorough understanding than currently exists of rangeland vegetation dynamics, how pastoralists' actions affect them, and, in turn, how pastoralists respond to social, economic, and policy incentives.

Acknowledgements

Major support for my work on the QTP came from the Robert M. Lee Foundation. I thank J. M. Andereis, D. Bedunah, D. J. Miller, A. Smith, E. Yeh, and an anonymous reviewer for ideas and improvements to the manuscript.

References

Bai, W.Q., Zhang, Y.L., Xie, G.D., Shi, Z.X., 2002. Analysis of formation causes of grassland degradation in Maduo county, in the source of the Yellow River. Chinese Journal of Applied Ecology 13, 823–826 (in Chinese).

Baker, B.B., Moseley, R.K., 2007. Advancing treeline and retreating glaciers: implications for conservation in Yunnan, P.R. China. Arctic, Antarctic, and Alpine Research 39, 200–209.

Banks, T.J., 2001. Property rights and the environment in pastoral China: Evidence from the field. Development and Change 32, 717–740.

Banks, T.J., 2003. Property rights reform in rangeland China: dilemmas on the road to the household ranch. World Development 31, 2129–2142.

Banks, T.J., Richard, C., Li, P., Yan, Z.L., 2003. Governing the grasslands of Western China. Mountain Research and Development 23, 132–140.

Bedunah, D.J., Harris, R.B., 2002. Past, present & future: rangelands in China. Rangelands 24, 17–22.

Berry, L., 2003. Land Degradation in China: Its Extent and Impact. China LD Case Studies. Land Degradation Assessment in Drylands, May 5, 2003. http://lada.virtualcentre.org/eims/approver/pub_dett.asp?pub_id = 92084&app = 0&section = description (accessed 01.11.04).

Bian, J.H., Jing, Z.C., Fan, N.C., 1999. The effect of grassland fencing on the population density of plateau pikas. Acta Biologica Plateau Sinica 14, 110–115 (in Chinese).

Bräuning, A., Mantwill, B., 2004. Summer temperature and summer monsoon history on the Tibetan plateau during the last 400 years recorded by tree rings. Geophysical Research Letters 31, L24205.

Chen, R.S., Kang, E.S., Yang, J.P., Lan, Y.C., Zhang, J.S., 2002. Variance tendency in the fifty-year annual meteorological and hydrological series of Hexi Region of Gansu Province. Journal of Lanzhou University (Natural Sciences) 38, 163–170 (in Chinese).

Chen, S., 1996. Inner Asian grassland degradation and plant transformation. In: Humphrey, C., Sneath, D. (Eds.), Cultural and Environment in Inner Asia, vol. 1: The Pastoral Economy and the Environment. The White Horse Press, Cambridge, UK, pp. 111–123.

Chen, S.B., Liu, Y.F., Thomas, A., 2006. Climatic change on the Tibetan Plateau: Potential evapotranspiration trends, 1961–2000. Climatic Change 76, 291–319.

Cheng, G.D., Wu, T.H., 2007. Responses of permafrost to climate change and their environmental significance, Qinghai-Tibet Plateau. Journal of Geophysical Research-Earth Surface 112.

Chu, D., Lu, L.X., Zhang, T.J., 2007. Sensitivity of normalized difference vegetation index (NDVI) to seasonal and interannual climate conditions in the Lhasa area, Tibetan Plateau, China. Arctic, Antarctic, and Alpine Research 39, 635–641.

Cincotta, R.P., Zhang, Y.Q., Zhou, X.M., 1992. Transhumant alpine pastoralism in northeastern Qinghai province: an evaluation of livestock population response during China's agrarian economic reform. Nomadic Peoples 30, 3–25.

Clarke, G.E., 1995. Socio-economic change and the environment in a pastoral area of Lhasa municipality. pp. 97–119. In: Development, Society and Environment in Tibet. Clarke, G.E. (Ed.), Proceedings of the Seventh Seminar of the International Association for Tibetan Studies. Graz. Verlag der Österreichischen Akademie der Wissenchasften, Vienna.

Davidson, G., Behnke, R.H., Kerven, C., 2008. Implications of rangeland enclosure policy on the Tibetan plateau. UPDATE Magazine No.2, October 2008. International Human Dimensions Programme on Global Environmental Change, 59–62.

Deng, A., 2005. Research on Ecological Economics of Pastoral Grasslands on the Qinghai-Tibet Plateau. People's Publishing House, Beijing, 292 pp. (in Chinese).

Deng, P.H., Liang, H.M., 2003. Causes and control of natural grassland degradation in the Aba region, Sichuan. Sichuan Livestock and Veterinary Science 7 (in Chinese).

Domrös, M., Schäfer, D., 2003. Recent climate change in China – statistical analyses of temperature and rainfall records. pp. 371–74. In: Terra Nostra, 2003/6, Klimavariabilität, Schriften der Alfred-Wegener-Stiftung.

Dong, Q.M., Zhao, X.Q., Ma, Y.S., Li, Q.Y., Wang, Q.J., Shi, J.J., 2005. Studies on the relationship between grazing intensities for yaks and plant groups in *Kobresia parva* alpine meadow. Acta Agrestia Sinica 13, 334–334, 343 (in Chinese).

Du, M.Y., Kawashima, S., Yonemura, S., Zhang, X.Z., Chen, S.B., 2004. Mutual influence between human activities and climate change in the Tibetan Plateau during recent years. Global and Planetary Change 41, 241–249.

Fan, N.C., Zhou, W.Y., Wei, W.H., Wang, Q.Y., Jiang, Y.J., 1999. Rodent pest management in the Qinghai-Tibet alpine meadow ecosystem. In: Singleton, G.R., Hinds, L.A., Leirs, H., Zhang, Z.B. (Eds.), Ecologically-based Management of Rodent Pests. Australian Centre for International Agricultural Research, Canberra, pp. 285–304.

Fischer, A.M., 2008. "Population invasion" versus urban exclusion in the Tibetan areas of western China. Population and Development Review 34, 631–662.

Foggin, J.M., 2000. Biodiversity protection and the search for sustainability in Tibetan plateau grasslands (Qinghai, China). Ph.D dissertation, Arizona State University, Tempe.

Foggin, J.M., 2008. Depopulating the Tibetan grasslands: national policies and perspectives for the future of Tibetan herders in Qinghai Province, China. Mountain Research and Development 28, 26–31.

Foggin, P.M., Foggin, M.E., Dorje, D., Xuri, W., Foggin, J.M., Torrance, J., 2006. Assessment of the health status and risk factors of Kham Tibetan pastoralists in the alpine grasslands of the Tibetan Plateau. Social Science and Medicine 63, 2512–2532.

Frauenfeld, O.W., Zhang, T.J., Serreze, M.C., 2005. Climate change and variability using European Centre for Medium-Range Weather Forecasts reanalysis (ERA-40) temperatures on the Tibetan Plateau. Journal of Geophysical Research 110, D02101.

Gao, X.Q., 1995. Preliminary analysis of climate changes in some regions of the northern part of the Qinghai-Xizang Plateau on a scale of decades. In: Evolution and Changes in the Geology, Environment and Ecosystems of the Tibetan Plateau. Science Press, Beijing, pp. 297–303 (in Chinese).

Gao, Y.H., Luo, P., Wu, N., Chen, H., Wang, G.X., 2007a. Grazing intensity impacts on carbon sequestration in an alpine meadow on the eastern Tibetan Plateau. Research Journal of Agriculture and Biological Sciences 3, 642–647.

Gao, Y.H., Luo, P., Wu, N., Yi, S.L., Chen, H., 2007b. Biomass and nitrogen responses to grazing intensity in an alpine meadow on the eastern Tibetan plateau. Polish Journal of Ecology 55, 469–479.

Gasse, F., Fontes, J.Ch., Van Campo, E., Wei, K., 1996. Holocene environmental changes in Bangong Co-Basin (Western Tibet), Part 4. discussion and conclusions. Palaeogeography, Palaeoclimatology, Palaeoecology 120, 79–92.

Gemmer, M., Becker, S., Jiang, T., 2003. Detection and visualization of climate trends in China. www.uni_giessen.de.zeu/papers/discpap%2315.pdf (accessed 2003).

Goldstein, M.C., Beall, C.M., 2002. Changing patterns of Tibetan nomadic pastoralism. In: Leonard, W.R., Crawford, M.H. (Eds.), Human Biology of Pastoral Populations. Cambridge University Press, pp. 131–150.

Goldstein, M.C., Beall, C.M., Cincotta, R.P., 1990. Traditional nomadic pastoralism and ecological conservation on Tibet's Northern Plateau. National Geographic Research Reports 6, 139–156.

Gu, A.L., 2000a. Biodiversity of Tibet's rangeland resources and their protection. In: Wu, N., Miller, D.J., Lů, Z., Springer, J. (Eds.), Tibet's Biodiversity: Conservation and Management. China Forestry Press Publishing House, Beijing, pp. 94–100.

Gu, S.Z., 2000b. Approaches for sustainable development of agriculture and animal husbandry in Tibet. Resources Science 22, 44–49 (in Chinese).

Han, F., Ben, G.Y., Shi, S.B., Wang, Q.J., 1991. Effects of Stocking Rate on Plant Growth and Productivity of Alpine Meadow. In: Alpine Meadow Ecosystem, vol. 3. Science Press, Beijing (in Chinese)81–88.

Han, J.G., Zhang, Y.J., Wang, C.J., Bai, W.M., Wang, Y.R., Han, G.D., Li, L.H., 2008. Rangeland degradation and restoration management in China. The Rangeland Journal 30, 233–239.

Harris, R.B., 2007. Wildlife Conservation in China: Preserving the Habitat of China's Wild West. M.E. Sharpe, Inc.

Harris, R.B., Bedunah, D.J., 2001. Sheep vs. sheep: Argali and Livestock in western China. Unpublished final report. University of Montana, Missoula.

Ho, P., 1998. Ownership and control in Chinese rangeland management since Mao: a case study of the free-rider problem in pastoral areas in Ningxia. In: Vermeer, E.B., Pieke, F.N., Chong, W.L. (Eds.), Cooperative and Collective in China's Rural Development: Between State and Private Interests. M.E. Sharpe, Armonk, NY, pp. 196–235.

Ho, P., 2000. China's rangelands under stress: a comparative study of pasture commons in the Ningxia Hui Autonomous Region. Development and Change 31, 385–412.

Holzner, W., Kreichbaum, M., 2000. Pastures in south and central Tibet (China): methods for a rapid assessment of pasture conditions. Die Bodenkultur 51, 259–266.

Holzner, W., Kreichbaum, M., 2001. Pastures in south and central Tibet (China): probable causes of pasture degradation. Die Bodenkultur 52, 37–44.

Hou, X.Y., Shi, J.Z., 2002. Pastoral Grasses of Western China. Chemical Industry Press, Beijing (in Chinese).

Hu, Z.Z., Zhang, D.G., 2003. China's pasture resources. In: Suttie, J.M., Reynolds, S.B. (Eds.), Transhumant Grazing Systems in Temperate Asia. Plant Production and Protection Series 31. Food and Agriculture Organization of the United Nations, Rome, pp. 81–133.

Hulme, M., Zhao, Z.C., Jiang, T., 1994. Recent and future climate change in East Asia. International Journal of Climatology 14, 637–658.
Jin, H.J., Li, S.X., Cheng, G.D., Wang, S.L., Li, X., 2000. Permafrost and climatic change in China. Global and Planetary Change 26, 387–404.
Kang, X.C., Graumlich, L.J., Sheppard, P.R., 1997. Construction and preliminary analysis of a 1835 year sequence of annuli in the Dulan area of Qinghai. Chinese Science Bulletin 42, 1089–1091 (in Chinese).
Klein, J.A., Harte, J., Zhao, X.Q., 2004. Experimental warming causes large and rapid species loss, dampened by simulated grazing, on the Tibetan Plateau. Ecology Letters 7, 1170–1179.
Klein, J.A., Harte, J., Zhao, X.Q., 2007. Experimental warming, not grazing, decreases rangeland quality on the Tibetan plateau. Ecological Applications 17, 541–557.
Lai, C.H., Smith, A.T., 2003. Keystone status of plateau pikas (*Ochotona curzoniae*): effect of control on biodiversity of native birds. Biodiversity and Conservation 12, 1901–1912.
Levine, N.E., 1995. From nomads to ranchers: managing pasture among ethnic Tibetans in Sichuan. In: Clarke, G.E. (Ed.), Development, Society and Environment in Tibet, Proceedings of the Seventh Seminar of the International Association for Tibetan Studies, Graz. 1995. Verlag der Österreichischen Akademie der Wissenchasften, Vienna, pp. 69–119.
Li, C., Zhai, Q.G., Xu, F., Zhu, Z.Y., Wang, T.W., 2003a. Resources in grassland of northern Tibet and its evolutionary trend – a case study of the Zainza area. Geological Bulletin of China 22, 991–998 (in Chinese).
Li, J.B., Cook, W.E., D'Arrigo, R., Chen, F.H., Gou, X.H., Peng, J.F., Huang, J.G., 2008a. Common tree growth anomalies over the northeastern Tibetan Plateau during the last six centuries: implications for regional moisture change. Global Change Biology 14, 2096–2107.
Li, M.S., 1994. Characteristics and rational exploitation of Tibet's land resources. Journal of Natural Resources 9, 51–57 (in Chinese).
Li, X., Cheng, G.D., Jin, H.J., Kang, E.S., Che, T., Jin, R., Wu, L.Z., Nan, Z., Wang, T.J., Shen, Y.P., 2008b. Cryospheric change in China. Global and Planetary Change 62, 210–218.
Li, X.D., June 4, 2004. Maqu County's retire grazing, return to grass construction program moves forward smoothly. Gansu Daily (in Chinese).
Li, X.L., Huang, B.N., 1995. The causes of "black soil patch" grassland in Qinghai province and management countermeasures. Grasslands of China 4, 64–66 (in Chinese).
Li, X.L., Yuan, Q.H., Wan, L.Q., He, F., 2008c. Perspectives on livestock production systems in China. The Rangeland Journal 30, 211–220.
Li, X.L., Zhu, Z.H., Qiao, Y.M., Liu, W., 2001. Study on ramet modular of *Kobresia humilis* clones under different stocking intensities in alpine meadows. Qinghai Journal of Animal and Veterinary Sciences 31, 9–11 (in Chinese).
Li, X.R., Jia, X.H., Dong, G.R., 2006. Influence of desertification on vegetation pattern variations in the cold, semi-arid grasslands of Qinghai-Tibet Plateau, North-West China. Journal of Arid Environments 64, 505–522.
Li, Y.N., Guan, D.R., Zhao, L., Gu, S., Zhao, X.Q., 2005. Seasonal frozen soil and its effect on vegetation production in Haibei alpine meadow. Journal of Glaciology and Geocryology 27, 311–319 (in Chinese).
Li, Y.N., Zhao, X.Q., Zhao, L., Wang, Q.J., Shen, Z.W., 2003b. Analysis of vegetation succession and climate change in Haibei alpine marsh in the Qilian Mountains. Journal of Glaciology and Geocryology 25, 244–249 (in Chinese).
Lin, Z., Ping, C.L., Yang, D.Q., Cheng, G.D., Ding, Y.J., Liu, S.Y., 2004. Changes of climate and seasonally frozen ground over the past 30 years in Qinghai-Xizang (Tibetan) Plateau, China. Global and Planetary Change 43, 19–31.
Ling, H., 2000. Status of grassland degradation in the major grazing areas of Tibet and measures of recovery. In: Wu, N., Miller, D.J., Lů, Z., Springer, J. (Eds.), Tibet's Biodiversity: Conservation and Management. China Forestry Press, Beijing, pp. 101–105.
Liu, J.K., Wang, X., Liu, W., Nie, H.Y., 1991. Effect of Experimental Grazing Level of Tibetan Sheep on Rodent Communities: Analysis of Structure and Function of Rodent Communities. In: Alpine Meadow Ecosystem, vol. 3. Science Press, Beijing (in Chinese)9–22.
Liu, J.K., Zhang, Y.Z., Xin, G.W., 1980. Relationship between numbers and degree of harmfulness of plateau pika. Acta Zoologica Sinica 26, 378–385 (in Chinese).
Liu, X.D., Chen, B.D., 2000. Climatic warming in the Tibetan Plateau during recent decades. International Journal of Climatology 20, 1729–1742.
Liu, X.H., Shao, X.M., Wang, L., Liang, E.Y., Qin, D.H., Ren, J.W., 2008. Response and dendroclimatic implications of $\delta^{13}C$ in tree rings to increasing drought on the northeastern Tibetan Plateau. Journal of Geophysical Research 113, G03015.
Liu, W., Wang, Q.J., Wang, X., Zhou, L., Li, Y.F., Li, F.J., 1999a. Ecological process of forming "black-soil type" degraded grassland. Acta Agrestia Sinica 7, 300–307 (in Chinese).
Liu, W., Zhou, L., Wang, X., 1999b. Responses of plant and rodents to different grazing intensity. Acta Ecologica Sinica 19, 376–382 (in Chinese).
Lobsang, 1998. The development of animal husbandry on the Qinghai-Tibetan Plateau. In: Clarke, G.E. (Ed.), Development, Society and Environment in Tibet, Proceedings of the Seventh Seminar of the International Association for Tibetan Studies, Graz 1995. Verlag der Österreichischen Akademie der Wissenchasften, Vienna, pp. 77–78.
Lu, L.Z., Lu, D.L., 2004. Discussion on the development of no-polluted mutton-beef production base in Qinghai Province after entry to the WTO. In: Li, P.C., Wang, W.K., Pei, X.Z. (Eds.), International Symposium on Environmental Protection and Sustainable Development in West China. China Environmental Science Press, Beijing, pp. 204–209 (in Chinese).
Lu, K.S., 2002. Grassland, Range, and Pasture in China. Kaiming Press, Beijing (in Chinese).
Luosan, L., 1996. Development and Environment of the Qinghai-Tibet Plateau. China Tibetan Studies Publishing, Beijing (in Chinese).
Ma, S.Z., Peng, M., Chen, G.C., Zhou, G.Y., Sun, Q., 2004. Feature analysis of vegetation degradation on alpine grasslands in the Yellow River source regions. Pratacultural Science 10, 19–23 (in Chinese).
Miller, D.J., 1999. Nomads of the Tibetan Plateau rangelands in western China, part three: Pastoral development and future challenges. Rangelands 21 (2), 17–20.
Miller, D.J., 2002. The importance of China's nomads. Rangelands 24, 22–24.
Miller, D.J., 2005. The Tibetan steppe. Plant Production and Protection Series No. 34. In: Suttie, J.M., Reynolds, S.G., Batello, C. (Eds.), Grasslands of the World. UN Food and Agriculture Organization, Rome, pp. 305–342.
Miller, D.J., Bedunah, D.J., Pletscher, D.H., Jackson, R.M., 1992. From open range to fences: changes in the range-livestock industry on the Tibetan Plateau and implications for development planning and wildlife conservation. In: Perrier, G.K., Gay, C.W. (Eds.), Proceedings of the 1992 International Rangeland Development Symposium, February 11–12, 1992, pp. 95–109. Spokane, Washington.
Northern Grassland Resource Survey Office, 1981. Outline and Technical Procedures for Monitoring Key Pastoral Grassland Resources. Northern Grassland Resource Survey Office, Beijing (in Chinese).
Nyima, T. 2003. China case study 3: Pastoral systems, change, and the future of grazing lands in Tibet. pp. 151–187 in Suttie J.M.. and Reynolds S.B. Transhumant Grazing Systems in Temperate Asia. Plant Production and Protection Series 31. Food and Agriculture Organization of the United Nations. Rome.
Oelke, C., Zhang, T.J., 2007. Modeling the active-layer depth over the Tibetan Plateau. Arctic, Antarctic, and Alpine Research 39, 714–722.
Pech, R.P., Jeibu, Arthur, A.D., Zhang, Y.M., Lin, H., 2007. Population dynamics and responses to management of plateau pikas *Ochotona curzoniae*. Journal of Applied Ecology 44, 615–624.
Perrement, M., 2006. Resettled Tibetans "can't live on charity forever". China Development Brief. www.chinadevelopmentbrief.com/node/573 (accessed 04.05.06).
Perryman, A., 2001. Changes in a vegetation index, 1982–1999. In: van Wageningen, N., Sa, W.J. (Eds.), The Living Plateau; Changing Lives of Herders in Qinghai. Concluding Seminar of the EU-China Qinghai Livestock Development Project. ICIMOD, Kathmandu, Nepal, pp. 11–24.
Piao, S.L., Fang, J.Y., 2002. Terrestrial net primary production and its spatio-temporal patterns in Qinghai-Xizang Plateau, China during 1982–1999. Journal of Natural Resources 17, 373–380 (in Chinese).
Piao, S.L., Fang, J.Y., Ji, W., Guo, Q.H., Ke, J.Y., Tao, S., 2004. Variation in a satellite-based vegetation index in relation to climate in China. Journal of Vegetation Science 15, 219–226.
Piao, S.L., Fang, J.Y., He, J.S., 2006. Variations in vegetation net primary production in the Qinghai-Xizang Plateau, China, from 1982 to 1999. Climatic Change 74, 253–267.
Pu, J.C., Yao, T.D., Yang, M.X., Tian, L.D., Wang, N.L., Yutaka, A., Fujita, K., 2007. Rapid decrease of mass balance observed in the Xiao (Lesser) Dongkemadi Glacier, in the central Tibetan Plateau. Hydrological Processes 22, 2952–2958.
Qian, W.H., Lin, X., 2004. Climate Research. Regional trends in recent temperature indices in China 27, 119–134.
Qin, N.S., Shao, X.M., Jin, L.Y., Wang, Q.C., Zhu, X.D., Wang, Z.Y., Li, J.B., 2003. Climate change over southern Qinghai plateau in the past 500 years recorded in *Sabina tibetica* tree rings. Chinese Science Bulletin 48, 2068–2072.
Qinghai Province, 2003. The Situation Regarding Qinghai Province's Retire Pastures Restore Grassland Demonstration Project, 2003. Qinghai Agriculture Bureau, Xining (in Chinese).
Richard, C., Yan, Z.L., Du, G.Z., 2006. The Paradox of the Individual Household Responsibility System in the Grasslands of the Tibetan Plateau, China. USDA Forest Service Proceedings RMPS-P-39. USDA Forest Service, Fort Collins, CO.
Rikiishi, K., Nakasato, H., 2006. Height dependence of the tendency for reduction in seasonal snow cover in the Himalaya and the Tibetan Plateau region, 1966–2001. Annals of Glaciology 43, 369–377.
Riley, N.E., 2004. China's population: new trends and challenges. Population Bulletin 59, 1–36.
Shang, Z.H., Long, R.J., 2005. Formation causes and recovery of the "black soil type" degraded alpine grassland in Qinghai-Tibetan Plateau. Chinese Journal of Ecology 24, 652–656 (in Chinese).
Sheehy, D., 2001. The Rangelands, land degradation and Black Beach. In: van Wageningen, N., Sa, W.J. (Eds.), The Living Plateau; Changing Lives of Herders in Qinghai. Concluding Seminar of the EU-China Qinghai Livestock Development Project. ICIMOD, Kathmandu, Nepal, pp. 5–9.
Shen, D.J., Varis, O., 2001. Climate change in China. Ambio 30, 381–383.
Shen, Y.Y., Ma, Y.S., Li, Q.Y., 2004. Grassland restoration in Dari County, Qinghai Province. In: Katsigris, E., Xu, J., White, T.A. (Eds.), Implementing the Natural Forest Protection Program and the Sloping Lands Conversion Programs: Lessons and Policy Implications, CCICED-WCFGTF. Beijing Forestry Publishing House, Beijing, pp. 303–340.
Sheppard, P.R., Tarasov, E., Graumlich, L.J., Heussner, K.-U., Wagner, M., Österle, H., Thompson, L.G., 2004. Annual precipitation since 515 BC reconstructed from living and fossil juniper growth of northeastern Qinghai Province, China. Climate Dynamics 23, 869–881.

Shi, Y.F., Yu, G., Liu, X.D., Li, B.Y., Yao, T.D., 2001. Reconstruction of the thirty to forty Ka BP enhanced Indian monsoon climate based on geological records from the Tibetan Plateau. Palaeogeography, Palaeoclimatology, Palaeoecology 169, 69–83.
Shi, Y.Z., 1983. On the influences of rangeland vegetation on the density of plateau pika (*Ochotona curzoniae*). Acta Theriologica Sinica 3, 181–187 (in Chinese).
Simpson, J.R., Cheng, X., Miyazaki, A., 1994. China's Livestock and Related Agriculture: Projections to 2025. CAB International, Wallingford, UK.
Smith, A.T., Foggin, J.M., 1999. The plateau pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan Plateau. Animal Conservation 2, 235–240.
Smith, A.T., Zahler, P., Hinds, L.A., 2006. Ineffective and unsustainable poisoning of native small mammals in temperate Asia: a classic case of the science-policy divide. In: McNeely, J.A., McCarthy, T.M., Smith, A.T., Olsvig-Whittaker, L., Wikramanayake, E.D. (Eds.), Conservation Biology in Asia. Society for Conservation Biology, Asia Section and Resources Himalaya Foundation, Kathmandu, Nepal, pp. 285–293.
State Council, 2002. Some suggestions regarding strengthening grassland protection and construction. State Council Circular 19 (in Chinese).
State Environmental Protection Agency Nature Reserve Bureau (SEPA), 1999. Report on China's Ecological Problems. China Environmental Sciences Press, Beijing (in Chinese).
State Environmental Protection Agency Nature Reserve Bureau (SEPA), 2006. Grasslands. SEPA website, July 27, 2006 (in Chinese).
State Environmental Protection Agency Nature Reserve Bureau (SEPA), 2007. Report on environmental 2006: Grasslands. SEPA website, June 18, 2007 (in Chinese).
Walker, B.H., Gunderson, L.H., Kinzig, A.P., Folke, C., Carpenter, S.R., Schultz, L., 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecology and Society 11 (1), 13. http://www.ecologyandsociety.org/vol11/iss1/art13 [online].
Wang, G.X., Cheng, G.D., 2001. Characteristics of grassland and ecological changes of vegetation in the source region of the Yangtze and Yellow Rivers. Journal of Desert Research 21, 101–107 (in Chinese).
Wang, G.X., Li, Y.S., Wu, Q.B., Wang, Y.B., 2006a. Relationships between permafrost area on the Qinghai-Tibetan plateau and vegetation, and influence on high, cold ecosystems. China Science D: Earth Sciences 36, 743–754 (in Chinese).
Wang, G.X., Wang, Y.B., Li, Y.S., Cheng, H.Y., 2007. Influences of alpine ecosystem responses to climatic change on soil properties on the Qinghai-Tibet Plateau, China. Catena 70, 506–514.
Wang, G.W., Li, Y.S., Hu, H.C., Wang, Y.B., 2008a. Synergistic effect of vegetation and air temperature changes on soil water content in alpine frost meadow soil in the permafrost region of Qinghai-Tibet. Hydrological Processes 22, 3310–3320.
Wang, H., Zhou, X.L., Wan, C.G., Fu, H., Zhang, F., Ren, J.Z., 2008b. Eco-environmental degradation in the northeastern margin of the Qinghai–Tibetan Plateau and comprehensive ecological protection planning. Environmental Geology 55, 1135–1147.
Wang, Q.J., Zhou, L., Wang, F.G., 1995. Effect analysis of stocking intensity on the structure and function of plant community in winter-spring grassland. In: Alpine Meadow Ecosystem, vol. 4. Science Press, Beijing (in Chinese)353–364.
Wang, S.L., 1993. Preliminary investigations on the relationship between grassland degradation on the eastern Qinghai-Tibetan plateau and permafrost. Dynamic Web of Eco-Environmental Research 4, 24–27 (in Chinese).
Wang, S.L., 1997. Study of permafrost degradation on the Qinghai-Xizang plateau. Advances in Earth Science 12, 164–167 (in Chinese).
Wang, S.L., Jin, H.J., Li, S.X., Zhao, L., 2000. Permafrost degradation on the Qinghai-Tibet Plateau and its environmental impacts. Permafrost and Periglacial Processes 11, 43–53.
Wang, X.H., Zheng, D., 1999. Sustainable use of alpine meadow grassland resources on the Qinghai-Tibetan plateau. Resource Sciences 21, 38–42 (in Chinese).
Wang, X.H., Han, X.Y., Bennett, J., 2004. Sustainable Land Use Change in the North West Provinces of China. Research Report 1, Australian Centre for International Agricultural Research (ACIAR) Project: ADP/2002/021, ISSN: 1449-7433. http://apseg.anu.edu.au/pdf/staff_pdf/bennett/china_land_use (accessed 05.01.05).
Wang, X.H., Zheng, Z.D., Shen, Y.C., 2008c. Land use change and its driving forces on the Tibetan Plateau during 1990–2000. Catena 72, 56–66.
Wang, W.Y., Wang, Q.J., Wang, H.C., 2006b. The effect of land management on plant community composition, species diversity, and productivity of alpine *Kobresia* meadow. Ecological Research 21, 181–187.
Wang, Y.B., Wang, G.X., Sheng, Y.P., Wang, W.L., 2005. Degradation of the eco-environmental system in alpine meadow on the Tibetan plateau. Journal of Glaciology and Geocryrology 27, 634–640 (in Chinese).
Wang, Y.X., Liu, G.Y., Zhang, X., Li, C.F., 1982. Tree rings of Qilian Mountains juniper trees and their relationship to China's climate change and glacial advance and retreat during the past thousand years. Chinese Science Bulletin 21, 1316–1319 (in Chinese).
Williams, D.M., 1996. Grassland enclosures: catalyst of land degradation in Inner Mongolia. Human Organization 55, 307–313.
Williams, D.M., 1997. The desert discourse of modern China. Modern China 23, 328–355.
Williams, D.M., 2002. Beyond Great Walls: Environment, Identity, and Development on the Chinese Grasslands of Inner Mongolia. Stanford University Press, Stanford, CA.
Wu, G.L., Du, G.Z., 2007. Discussion on ecological construction and sustainable development of degraded alpine ecosystem of the Qinghai-Tibetan plateau. Nature Journal 29, 159–169 (in Chinese).
Wu, N., Yan, Z.L., 2002. Climate variability and social vulnerability on the Tibetan Plateau: Dilemmas on the road to pastoral reform. Erdkunde 56, 2–14.
Wu, Q.B., Liu, Y.Z., 2004. Ground temperature monitoring and its recent change in Qinghai-Tibetan Plateau. Cold Regions Science and Technology 38, 85–92.
Wu, Q.B., Lu, Z.J., Liu, Y.Z., 2006. Permafrost changes in the Tibetan Plateau. Advances in Climate Change Research 2 (Suppl. 1), 77–80.
Xin, L., Cheng, G.D., Jin, H.J., Kang, E.S., Che, T., Jin, R., Wu, L.Z., Nan, Z.T., Wang, J., Shen, Y.P., 2008. Cryospheric change in China. Global and Planetary Change 62, 210–218.
Xu, W.X., Liu, X.D., 2007. Response of vegetation in the Qinghai-Tibet Plateau to global warming. Chinese Geographical Science 17, 151–159.
Yan, J.P., 2001. Strategies and Countermeasures of China's Great Western Development Strategy. Science Press, Beijing (in Chinese).
Yan, Z.L., Li, G.R., Wu, N., 2000. A probe into the pastoral production system in Hongyuan, eastern Qinghai-Tibetan plateau. In: Proceedings of the Third International Yak Congress, Lhasa. ICIMOD, Kathmandu.
Yan, Z.L., Wu, N., Dorji, Yeshi, Ru, J., 2005. A review of rangeland privatization and its implications in the Tibetan Plateau, China. Nomadic Peoples 9 (1), 31–51.
Yang, B., Shi, Y.F., Bräuning, A., Wang, J.X., 2004a. Evidence for a warm-humid climate in arid northwestern China during 40–30 ka BP. Quaternary Science Reviews 23, 2537–2548.
Yang, M.X., Wang, S.L., Yao, T.D., Gou, X.H., Lu, A.X., Guo, X.J., 2004b. Desertification and its relationship with permafrost degradation in Qinghai-Xizang (Tibet) plateau. Cold Regions Science and Technology 39, 47–53.
Yang, W., Yao, T.D., Xu, B.Q., Wu, G.J., Ma, L.L., Xin, X.D., 2008. Quick ice mass loss and abrupt retreat of the maritime glaciers in the Kangri Karpo Mountains, southeast Tibetan Plateau. Chinese Science Bulletin 53, 2547–2551.
Yao, T.D., Pu, J.C., Lu, A.X., Wang, Y.Q., Yu, W.S., 2007. Recent glacial retreat and its impact on hydrological processes on the Tibetan Plateau, China, and surrounding regions. Arctic, Antarctic, and Alpine Research 39, 642–650.
Ye, C., Dai, S.G., 2004. Drying Trends on the Qinghai-Tibet Plateau, September 18, 2004. www.stdaily.com.
Yeh, E.T., 2003. Tibetan range wars: spatial politics and authority on the grasslands of Amdo. Development and Change 34 (3), 499–523.
Yeh, E.T., 2005. Green governmentality and pastoralism in Western China: 'Converting pastures to grasslands'. Nomadic Peoples 9, 9–30.
Yi, S.L., Wu, N., Luo, P., Wang, Q., Shi, F.S., Zhang, Q.Y., Ma, J.Z., 2008. Agricultural heritage in disintegration: trends of agropastoral transhumance on the southeast Tibetan Plateau. International Journal for Sustainable Development & World Ecology 15, 273–282.
Yu, F.F., Price, K.P., Ellis, J., Shi, P.J., 2003. Response of seasonal vegetation development to climatic variations in eastern central Asia. Remote Sensing of Environment 87, 42–54.
Yu, X.G., 2003. Research on Sustainable Development in the Yangtze River Region. Science Press, Beijing (in Chinese).
Zeng, Y.N., Feng, Z.D., Cao, G.C., 2003. Land cover change and its environmental impact in the upper reaches of the Yellow River, Northeast Qinghai-Tibet Plateau. Mountain Research and Development 23, 353–361.
Zhang, H.F., Liu, F.G., Zhou, Q., Duo, H.R., 2004. Degradation mechanism of the grass in Qinghai Plateau and its prevention and control countermeasures. Journal of Natural Disasters 13, 115–120 (in Chinese).
Zhang, J.H., Yao, F.M., Zheng, L.Y., Yang, L.M., 2007. Evaluation of grassland dynamics in the northern-Tibet Plateau of China using remote sensing and climate data. Sensors 7, 3312–3328.
Zhang, T.J., 2007. Perspectives on environmental study of response to climatic and land cover/land use change over the Qinghai-Tibetan Plateau: an introduction. Arctic, Antarctic, and Alpine Research 39, 631–634.
Zhang, Y.M., Zhang, Z.B., Liu, J.K., 2003. Burrowing rodents as ecosystem engineers: the ecology and management of plateau zokors *Myospalax fontanierii* in alpine meadow ecosystems on the Tibetan Plateau. Mammal Review 33, 284–294.
Zhang, Y.Q., Welker, J.M., 1996. Tibetan alpine tundra responses to simulated changes in climate: aboveground biomass and community responses. Arctic and Alpine Research 28, 203–209.
Zhang, Z.H., Wu, X.D., 1997. Using tree annuli to recover the past 700 years' climate change in the Qilian Mountain area. Chinese Science Bulletin 42, 849–851 (in Chinese).
Zhang, Z.X., 2004. Qinghai Geography. Qinghai People's Publishing House, Xining (in Chinese).
Zhao, L., Ping, C., Yang, D., Cheng, G.D., Ding, Y., Liu, L., 2004. Changes of climate and seasonally frozen ground over the past 30 years in Qinghai-Xizang (Tibetan) Plateau, China. Global and Planetary Change 43, 19–31.
Zhao, X.Q., Wang, Q.J., Pi, N.L., 1988. Principal components analysis of herbage resources utilized by Tibetan sheep under different stocking rates on alpine meadow. Acta Biologica Plateau Sinica 8, 89–95.
Zhao, X.Q., Zhang, Y.S., Zhou, X.M., 2000. Theory and practice for sustainable development of animal husbandry on the alpine meadow pasture. Resources Science 22, 50–61 (in Chinese).
Zhao, X.Q., Zhou, H.K., 2005. Eco-environmental degradation, vegetation regeneration and sustainable development in the headwaters of the three rivers on the Tibetan plateau. S&T and Society 20, 471–476 (in Chinese).
Zhou, H.K., Zhao, X.Q., Tang, Y.H., Gu, S., Zhou, L., 2005a. Alpine grassland degradation and its control in the source region of the Yangtze and Yellow Rivers, China. Grassland Science 51, 191–203.
Zhou, H.K., Zhao, X.Q., Tang, Y.H., Zhou, L., Liu, W., Yu, L., 2004. Effect of long-term grazing on alpine shrub vegetation on the Qinghai-Tibet Plateau. Grasslands of China 26, 1–11 (in Chinese).

Zhou, H.K., Zhao, X.Q., Zhou, L., Liu, W., Li, Y.N., Tang, Y.H., 2005b. A study on correlations between vegetation degradation and soil degradation in the alpine meadow of Qinghai-Tibetan plateau. Acta Prataculturae Sinica 14, 31–40 (in Chinese).

Zhou, H.K., Zhou, L., Zhao, X.Q., Liu, W., Yan, Z.L., Shi, Y., 2003. Degradation process and integrated treatment of ‘‘black soil beach'' grasslands in the source regions of the Yangtze and Yellow Rivers. Chinese Journal of Ecology 22, 51–55 (in Chinese).

Zhou, H.K., Zhou, L., Zhao, X.Q., Yan, Z.L., Liu, W., Shi, Y., 2002. Influence of grazing disturbance on alpine grassland. Grasslands of China 24, 53–60 (in Chinese).

Zhou, L., Wang, Q.J., Zhao, J., Zhou, Q., 1995a. Studies on Optimum Stocking Intensity in Pasturelands of Alpine Meadow. I. Stocking Intensity to Maximize Production of Tibetan Sheep. In: Alpine Meadow Ecosystem, vol. 4. Science Press, Beijing (in Chinese)365–375.

Zhou, L., Wang, Q.J., Zhao, J., Zhou, Q., 1995b. Studies on Optimum Stocking Intensity in Pasturelands of Alpine Meadow. IV. The Measuring of Vegetation Change and the Maximum Stocking Intensity of Non-degenerated Grasslands. In: Alpine Meadow Ecosystem, vol. 4. Science Press, Beijing (in Chinese)403–418.

Zhou, X.M., 2001. China's *Kobresia* Meadows. Science Press. Beijing (in Chinese).

Zhou, X.M., Pi, N.L., Zhou, X.Q., Zhang, S.L., Zhao, D.H., 1986. Preliminary study on optimum stocking rate in alpine meadow. Acta Biological Plateau Sinica 5, 21–24 (in Chinese).

Zhu, Z.H., Wang, G., Zhao, S.L., 1994. Dynamics and regulation of clonal ramet populations of *Kobresia humilis* under different stocking intensities. Acta Ecologica Sinica 14, 40–45 (in Chinese).