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Commentary

Socio-Environmental Dynamics of Alpine Grasslands, Steppes and Meadows of the Qinghai–Tibetan Plateau, China: A Commentary

Haiying Feng [1,*] and Victor R. Squires [2,*]

1 Qinzhou Development Research Institute, Beibu Gulf University, Qinzhou 535011, China
2 Faculty of Natural Resources, Formerly University of Adelaide, Adelaide, SA 5005, Australia
* Correspondence: fhy@bbgu.edu.cn (H.F.); squires200@yahoo.com.au (V.R.S.)

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Abstract: Alpine grasslands are a common feature on the extensive (2.6 million km^2) Qinghai–Tibet plateau in western and southwestern China. These grasslands are characterized by their ability to thrive at high altitudes and in areas with short growing seasons and low humidity. Alpine steppe and alpine meadow are the principal plant Formations supporting a rich species mix of grass and forb species, many of them endemic. Alpine grasslands are the mainstay of pastoralism where yaks and hardy Tibetan sheep and Bactrian camels are the favored livestock in the cold arid region. It is not only their importance to local semi nomadic herders, but their role as headwaters of nine major rivers that provide water to more than one billion people in China and in neighboring countries in south and south-east Asia and beyond. Grasslands in this region were heavily utilized in recent decades and are facing accelerated land degradation. Government and herder responses, although quite different, are being implemented as climate change and the transition to the market economy proceeds apace. Problems and prospects for alpine grasslands and the management regimes being imposed (including sedentarization, resettlement and global warming are briefly discussed.

Keywords: endemism; floristics; nomadic; yaks; livestock; culture; altitude; watersheds; rivers; biodiversity; grassland management; land degradation; rodents; policy; interventions

1. Introduction

This study is a brief overview and synthesis of key points relating to the dynamics of alpine grasslands on the high-altitude and generally arid Qinghai–Tibet Plateau (QTP). It presents a synthesis of what is known about the key issues relating to alpine grasslands and the people, both locally and in distant countries, who depend on the ecosystem goods and services the grasslands provide. Many people use the grassland daily for their lives and livelihoods in this remote and harsh environment. Its purpose is to introduce the region and highlight aspects of the biogeography, ecology, climatology and demography that make this region on the "Roof of the World" or the "Third Pole" such an important one that provides water to about two billion people. In China itself, hundreds of millions rely on the rivers that arise on the QTP to provide water for irrigation, industrial uses, navigation and domestic water supply. Many hundreds of millions of people who live in countries in South Asia and South-east Asia are utterly dependent on flows along the Mekong, Brahmaputra and the other major rivers that arise on the QTP. The QTP supports millions of semi-nomadic herders and their livestock in Qinghai and in Tibet where livestock such as yak, hardy Tibetan sheep and Bactrian camels provide the sole source of sustenance and income.

Regrettably, anthropogenic environmental degradation (Figure 1)—exacerbated by changing climate [1], is accelerating as populations of both people and livestock rise [2], and policy measures designed to protect biodiversity and watersheds are implemented. Climate change, overgrazing and other reasons caused continuous degradation of alpine grasslands (see below). Several categories of alpine grassland are recognized based on the botanical composition and species diversity (see below). The management regimes under which they are used has changed a lot in the past 80 years (see below) and land degradation is now a major concern.

Figure 1. Land degradation on the cold and arid Qinghai–Tibet Plateau has accelerated in response to rising pressure from increasing populations of people (inward migration, natural increase) and of livestock (photo: H.Y. Feng).

Context and Setting

The QTP is the largest upland in the world and encompasses Xizang (Tibet) Qinghai province and parts of northern Yunnan and Sichuan provinces of China (Figure 2). Much of QTP is at an elevation above 2500 m above sea level (m ASL) and it includes Mt Everest and other high peaks of the Himalayan chain of mountains where elevations exceed 7000 m ASL. Of course, grassland vegetation, except for subnival cushion plants such as *Thylacospermum caespitosum* that can grow at elevations up to 6000 m ASL, is absent at elevations of above about 4500 m ASL.

The total area is approximately 2.6 million km^2 (about the size of Argentina or twice the area of Germany). The QTP is surrounded by massive mountain ranges. The QTP is bordered to the south by the Himalayan Range, to the north by the Kunlun Range which separates the QTP from the Hexi Corridor and the Gobi Desert that occupies parts of western Gansu, Xinjiang and parts of western Inner Mongolia even extending into neighboring Mongolia [3].

To the east and southeast the plateau gives way to the mountainous headwaters of nine of Asia's most important rivers (Figure 3) including the Mekong, Yangtze, Yellow, Salween and Brahmaputra rivers (Figure 3b). The QTP is home to the world's highest mountains and some of the world's cold deserts. The QTP is a high altitude, arid steppe interspersed with mountain ranges and large brackish lakes. Despite the extreme climate there are extensive areas of grasslands. Grasslands occupy about 60% of the land surface area of the QTP. Alpine grassland is a major ecosystem on the Qinghai–Tibet Plateau [4] playing an important role as an eco-safety barrier and serving as the basis of highland animal husbandry (Figures 3a and 4).

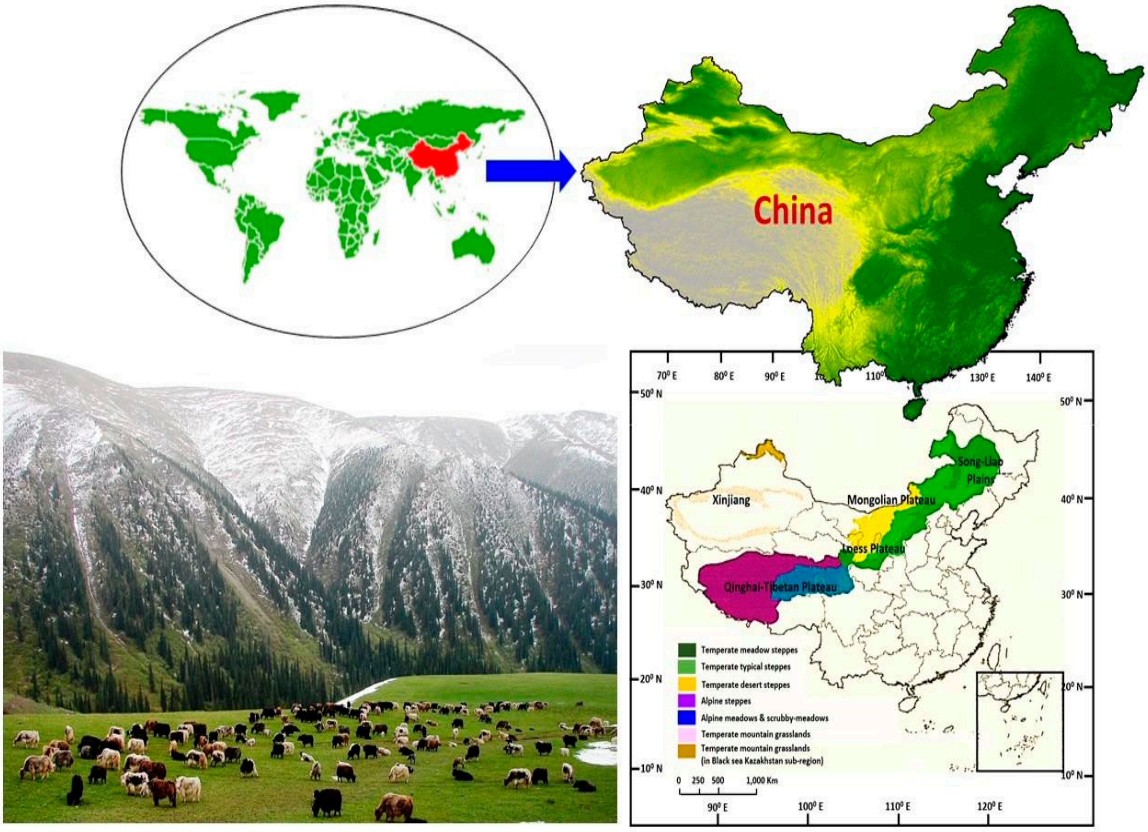

Figure 2. Maps showing right to left (clockwise) China (in red) in relation to the whole world, the location of the Qinghai–Tibet Plateau (QTP) in China (gray shaded area in SW of China) and the distribution inter alia of alpine steppes and alpine meadows on the QTP. The photo shows yaks grazing alpine grassland at an altitude of 4000 meters (photo: V.R. Squires).

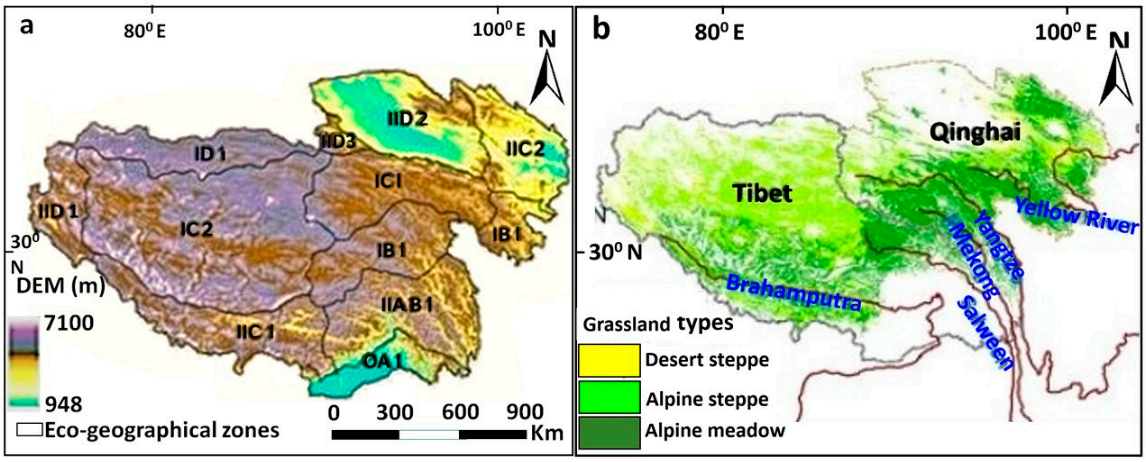

Figure 3. Map of Qinghai–Tibet Plateau showing (**a**) principal eco-geographical zones, elevation and (**b**) grassland types as well as the major rivers that arise on the Plateau. The relatively small areas of true alpine meadow are scattered throughout the lower altitude regions and are highly prized as grazing, especially by sheep herders (see Figure 4).

Figure 4. Alpine grasslands on the Qinghai–Tibet Plateau, especially alpine meadows, are prime grazing lands. Government policy is to regulate grazing pressure through imposition of grazing bans and restrictions on herder mobility (transhumance) (photo: V.R. Squires).

2. Origin of the Grasslands

In the recent review by Li et al. [5] it is argued that much of the contemporary natural grassland region was covered by subtropical forests and savanna woodlands during the Tertiary period. The grasslands formed as a consequence of the uplift of the QTP that blocked the monsoon rains from the south. The region became drier, favoring the gradual development of xerophilous steppes replacing the former mesophilous vegetation. The evolutionary history of biodiversity and endemism on the QTP is still debated, depending on differing hypotheses on highland uplift and climate history. Similarly, the history and intensity of human impact on Tibetan grasslands are still under discussion based on evidence from diverse disciplines [2,6,7].

The present day QTP supports various alpine vegetation types that include meadow, steppe, cold desert and subnival cushion plant communities [2,5] at elevations ranging from 3500 to nearly 6000 m above sea level (m ASL). The southern and eastern edges of the steppe have grasslands which can sustainably support populations of nomadic herdsmen. Frosts occur for six months of the year and there is permafrost under extensive parts of the region. Annual precipitation ranges from 100–300 mm and occurs mainly as hailstorms. Within the QTP, moisture determines whether a specific subregion supports meadow, steppe or alpine desert vegetation. Alpine (Here the word "alpine" does not strictly refer to a mountain climate which is not warm enough to allow for tree growth, here it indicates high-elevation distribution (see Box 1) Grassland is the dominant ecosystem covering over 50 per cent of the QTP [2,4,5,7]. Alpine steppes are commonly found on the QTP [8]. The grasslands on the QTP, including alpine steppes and meadows, are delimited as one alpine vegetation region [9,10]. The alpine steppes are distributed across the larger part of the QT Plateau, while the alpine meadows occur mainly on the southeastern parts, typically between 2500 and 4000 m ASL [10].

According to Li et al. [5] the QTP vegetation region has a very rich, diverse and often endemic flora. It comprises species of Central Asian (semi-) deserts, as well as temperate East Asian and Himalayan elements [8]. The dominant herbaceous species are not typically grasses but are frequently sedges from the genus *Kobresia* (Studies by Global Carex Group [11] suggest that the genus *Kobresia* should be included into *Carex*) and *Carex*, especially in alpine and subalpine meadows. A total of 5766 plant species have been documented for the Tibetan Autonomous Region [10]. More than 2000 of these species are recorded for the grassland region, of which 86% are forage plants and occur mainly in the more humid and sub-humid grasslands of eastern Tibet, while 540 species occur in the arid and semi-arid rangelands that lie further west [12,13]. The flora of alpine steppes consists of Eurasian steppe species (*Festuca kryloviana, F. pseudovina, Stipa glareosa, S. krylovii, S. bungaena*), as well as Central Asian alpine (*S. subsessiliflora*), Pamir–QTP (*S. purpurea, S. uroborowskyi, F. olgae, Carex moorcroftii*) and QTP endemics (*S. subsessiliflora* var. *basiplumosa* and *S. capillacea*) [11–13]. A 'snapshot' of the variety and distribution of key functional groups of alpine plants is shown in Table 1.

Table 1. Typical botanical composition in high elevation alpine grasslands # (percentage basis).

Functional Groups	Alpine Steppes			Alpine Desert Steppe		Alpine Meadow		Temperate Meadow Steppe
	Plains	**Slopes**	**Mountains**	**Slopes**	**Mountains**	**Slopes**	**Mountains**	**Plains**
Sedges/grasses	15.2/Tr.	28.5/Tr.	22.8/Tr.	48.5/Tr.	Tr./69.8	Tr.	40.70	Tr./3.87
Forbs (edible/inedible)	17.5	10.6	35.2	6.2	9.3	29.4	17.2	18.7/7.00 *
Legumes	Tr.	Tr.	Tr.	Tr.	4.05	2.45	Tr.	Tr.

Note. # data from sites scattered across Tibet (alpine steppe and alpine desert steppe) and Qinghai (alpine meadow and temperate meadow steppe). * Some forbs are toxic and/or unpalatable to livestock. In Temperate Meadow steppe 7.00 % is inedible. Tr. refers to trace amounts (<1%) Tr./3.87 refers to Tr. of sedge and 3.87 of grass. Data source: Feng, unpublished. This is a generalization based on numerous field surveys by H. Feng and her students over the past 10 years.

2.1. Understanding QTP Grassland Vegetation

From 1973 when the first comprehensive full-scale series of scientific expeditions for the QTP were initiated, much has been learned about the alpine grasslands of the QTP. Most data pertained to vegetation distribution using methods proposed by Ellenberg & Mueller-Dombois [14,15]. After 1992 several permanent monitoring stations were established at key sites to monitor eco-environmental changes on the QTP. A relatively complete monitoring and early warning system was set up that integrates air and land networks. A network developed for monitoring and studying earth surface processes and environment in extremely cold areas of high altitude. Observation networks exist that relate to environmental protection, land, agriculture, forestry, water conservancy, meteorology and some other fields. Under the Chinese ecosystem research network, observation stations (Figure 5) for eight different ecosystems, have been established on the QTP. Based on the earlier surveys and subsequent studies the following division of alpine grasslands has been suggested, as set out in 2.1 below. Meteorological stations and vegetation and land surface monitoring assists in devising revised policies for management of the vast areas of alpine pastures in the Study area (Qinghai–Tibet Plateau). Figure 3b shows the distribution of the three major alpine grassland types and there is a brief description of each, including listing of key plant species, in 3.1 below.

Our study area encompasses the vast tract of land (bigger than Spain) in southern and eastern QTP (Figure 5) although there were temporary field sites in the border areas near Tajikistan, Kyrgyzstan, Nepal, Bhutan and Myanmar. We did most of our botanical work on grasslands over a period of more than 12 years within a short radius of the monitoring stations (Figure 5) but our rural sociology work extended to herder communities further west into Tibet.

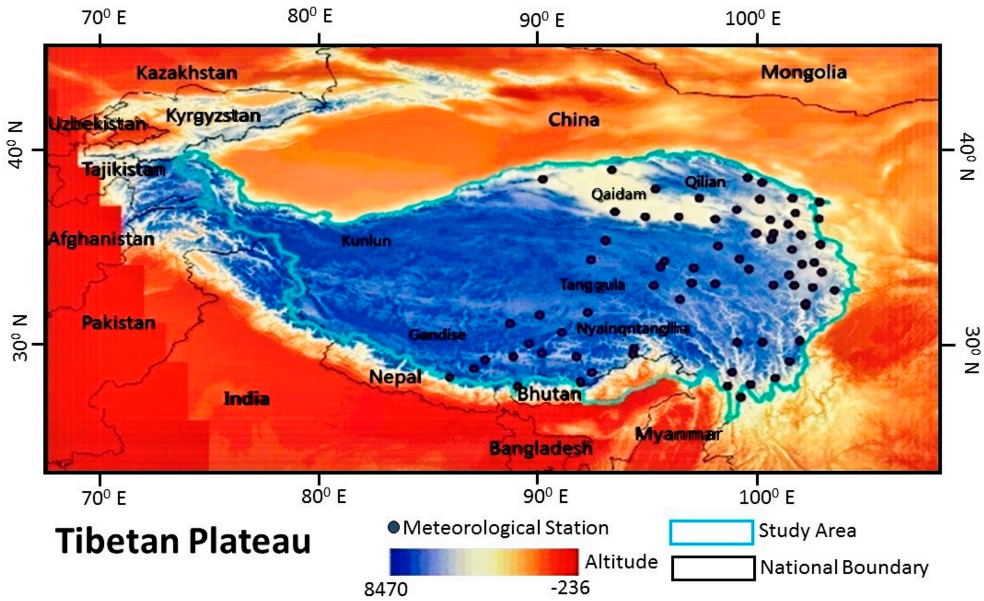

Figure 5. Qinghai–Tibet Plateau of China and the surrounding countries. Location of the monitoring stations is shown (Source: authors).

2.2. Types and Categories of Alpine Grasslands

Alpine steppes are mostly found at elevation between 3300 and 5300 m ASL on the QTP. The common dominant species are extremely cold- and drought-tolerant grasses and dwarf shrubs, with more or less pronounced admixture of cushion plants. The dominants include locally distributed species such as *Stipa subsessiliflora* var. *basiplumosa*, *S. roborowskyi*, *Festuca olgae*, *Carex moorcroftii*, *Orinus thoroldii O. kokonorica* and *Artemisia salsoloides* var. *wellbyi*; yet there also are common plants of Eurasian steppes such as *Festuca kryloviana* and *F. pseudovina* (Homophytic synonym is *Festuca pulchra*)**.**

Marshy meadows are, according to [5] "primarily composed of hygrophilous herbs and have transitional characteristics between a typical meadow and a marsh. Their occurrence is generally associated with high soil moisture regulated by special topographic factors, most often at poorly drained sites, thus with humid and poorly aerated soil". The existence of a permafrost layer is also a major cause for association of humid soil conditions and marshy meadows, such as on the QTP. Massive layers of humus and even peat or a semi-peat layer accumulate in soils of marshy meadows due to slow decomposition of plant residues. Examples of alpine marshy meadows include those dominated by *Kobresia tibetica* along streams or waterlogged areas over permafrost in the catchments of the Yellow River, Yangtze, Mekong and Salween. *Kobresia schoenoides* is, however, dominant along the Yarlung Zangbo River. *Carex schmidtii* or *Sanguisorba parviflora* dominate at the river flats adjacent to forest stands in Hinggan mountains in the eastern QTP.

Saline meadows are mainly composed of mesic perennial halophytes, that is, salt tolerant or otherwise adapted species and occur on salinized low-lying sites, wide valleys, fringes of lake basins and river flats within steppe and desert regions. Most widely distributed saline meadows include those dominated by *Achnatherum splendens*, *Leymus dasystachys*, *Phragmites communis*, *Sophora alopecuroides*, *Crypsis aculeate* and *Suaeda* spp.

Alpine meadows occur mainly on the eastern QTP and in part on the high mountains of northwestern China and northern China, under a cold–arid climate with intermediate humidity, adequate sunshine, intense solar radiance and strong winds. As Box 1 shows, the Chinese interpretation of 'meadow' differs from the more common usage.

Box 1. Meadows as defined in the Chinese context.

Meadows in classic European understanding are agriculturally managed grasslands regularly mown for livestock forage (UNESCO classification) [14,15]. In China, meadow refers to natural grasslands primarily composed of mesophilous perennial herbs that thrive under moderate moisture conditions. The meadows naturally occupy vast continuous areas with moderate moisture conditions that derive from atmospheric precipitation and with relatively low temperature that limits the growth of trees, such as alpine meadows on the QTP. However, in most other cases, meadows are azonal, occurring in the alpine, montane, plain and coastal areas of the temperate zones, with moisture originating from groundwater, runoff or melted snow and ice; these meadows are classified into typical, marshy and salt meadows, based on the ecological traits of their constituent species, that is, the dominance of mesophilous, xero-mesophilous, hygro-mesophilous or halo-mesophilous species in their composition [10,16,17].

Alpine meadow soils are shaped by intense soil-forming processes during pedogenesis and are characterized by the occurrence of semi-decomposed residual turf, closely interwoven root mats and a poorly intermingled humus layer. The *Kobresia* alpine meadows are the most typical and most widespread of the alpine meadows in China [2,4,5]. *Kobresia* species are both mesophilous and cold-and drought-tolerant. There are about 40 *Kobresia* species, dominant ones include *K.pygmaea*, *K. humilis*, *K. capillifolia*, *K. graminifolia*, *K. setchwanensis*, *K. prattii*, *K. royleana*, *K. smirnovii* and *K. bellardii.* There are also alpine meadows dominated by sedges such as *Carex scabriostris*, *Blysmus sinocompressus*, bunchgrasses such as *Festuca ovina, F. pseudovina, Poa alpina, Anthoxanthum odoratum and* forbs such as *Polygonum viviparum*, *P. sphaerostachyum*, *Ligularia virgaurea* and *Alchemilla japonica.*

The grasslands have vertical zonality [17] from relatively low altitude (2400 m ASL) to high altitude (>4500 m ASL). There is also horizontal zonality from south-east QTP to the northwest region [4,13,17]. The sequence includes alpine meadow, alpine steppe, desert steppe and alpine desert that include sand dunes. The dominant plants in these grasslands include at the lower elevations *Poa alpine, Festuca rubra, F. ovina* and a suite of forbs in the genera *Anemone, Ranunculus, Stellaria.* On drier/higher sites *Kobresia humilis, Leymus chinensis, Stipa baicalensis, Stipa grandis, Stipa kyrilovii, Artemisia frigida* and various cold and salt tolerant shrubs and subshrubs dominate. The botanical composition of alpine meadows depends to a large extent on the grazing pressure and seasonal management regime [1,10,18]. For example, Table 2 shows the list of common forage species and their ranking (based on abundance) in grasslands grazed under contrasting management regimes.

There was more sustained grazing pressure on the SH areas than on the MH sites because of the effect of trampling [18,19] and non-selective grazing. We measured the projected foliage cover to act as an indicator of grazing pressure along with biomass per m^2 and species abundance (Table 2). In the SH sites *Ligularia virgaurea* (9.3% ± 10% projected foliage cove [PFC]), *Anemone rivularis* var. *flore-minore* (5.4 ± 3.9 PFC) and *Taraxacum mongolicum* (5.3% ± 3.4% PFC) are regarded as indicators of land degradation because they are toxic or unpalatable plants that exploit gaps exposed by grazing pressure. Poisonous plants were observed to be more common on SH land. This suggests that the SH management regime may be causing further serious degradation and that productive forage species may be on the decline [20–22]. Field work to substantiate this is underway.

Apart from the actual management regime (where, when and the duration of grazing at any specific location) there is the grazing pressure or stocking rate. As Table 3 shows there is often a wide disparity between the actual and the recommended stocking rates. Because of the high altitude and short growing season, livestock are moved from the higher grasslands in summer and autumn to the cool season grasslands at lower altitudes (often referred to as winter pastures. herders typically have a 'winter residence' where livestock, principally yaks, can overwinter in the open [22,23].

Table 2. The most commonly found forage species in grassland grazed under two different systems. **SH** refers to an area where a single household makes all the decisions about when, where and how long to graze a specific site and **MH** refers to an area under a community-based management scheme where cooperating households follow a plan, including scheduled bans to allow rest rotation grazing.

Plant Species	SH g/m^2 ± SE	Rank # SH	MH g/m^2 ± SE	Rank MH
Anenome rivularis var. *flore-minore* (F)	5.9 (±3.6)	8	–	–
Elymus nutans (G)	13 (±16)	6		
Festuca sinensis (G)	14 (±8)	4	25 (±11)	2
Guildenstaedia diversifolia (L)			22 (±14)	4
Kobresia capillifolia (S)	22 (±21)	1	24 (±20)	3
Kobresia humilis (S)	4.1 (±1.7)	10 (eq.)		
Lancea tibetica (F)			19.3 (±10.7)	6
Poa pratensis (G)			20 (±12)	5
Potentilla fragarioides (F)	15.6 (±11)	3		8
Ligularia virguarea (F)	11.9 (±10.7)	7		
Ranunculus angustifolia var. *capillarus* (F)			12.9 (±9)	10
Scirpus distigmaticus (G)	19 (±17)	2	26 (±15)	1
Taraxacum mongolicum (F)	5.3 (±3.4)	10 (eq.)		
Thalicrum alpinum (F)	13 (±8.1)	5		

G—grass; **F**—forb; **S**—sedge; **L**—legume (highly preferred by livestock). # Rank is based on species abundance (measured as biomass and expressed as g/m^2). Source: Squires and Feng unpublished. Data collected from numerous sites (>70) within a long-term trial designed by Lanzhou University in Maduo county to compare two grazing regimes. The data show a high degree of variability but are enough to show the major trends.

Table 3. Contrast between practical stocking rate (S/R) and theoretical stocking rate of grassland in five counties in Qinghai (×10^4 sheep unit) *.

<table>
<tr><th>Area/County</th><th>Maduo</th><th>Maqin</th><th>Dari</th><th>Gande</th><th>Qumalai</th></tr>
<tr><td>Livestock number #</td><td>84.5</td><td>138.3</td><td>114.2</td><td>105.7</td><td>142.5</td></tr>
<tr><td>Theoretical S/R
In cool season</td><td>66.7</td><td>99.2</td><td>124.1</td><td>29.6</td><td>70.1</td></tr>
<tr><td>Theoretical S/R
In warm season</td><td>304.9</td><td>196.6</td><td>267.5</td><td>165.6</td><td>98.5</td></tr>
<tr><td>The ratio of duration of time spent
between the cool and warm season * area</td><td colspan="5">Around 2:1</td></tr>
</table>

Note: # One sheep unit is the equivalent of a 40-kg sheep. This enables different types and sizes of livestock to be expressed as a common unit using approved conversion ratios for goats, camels, yaks, horses, etc. * Cool and warm are relative terms. The cool season areas are at lower elevations and herds and their herders over-winter there. This is despite subzero temperatures for months on end. Data source: Feng unpublished, based on advice from local animal husbandry and grassland management bureaus in each county and a synthesis of published studies.

2.3. The Important Role of Alpine Meadows

Alpine grasslands, especially alpine meadows, make a huge contribution to the ecology and biodiversity of plants and animals (including microfauna) of the QTP and by extension, to the whole of China and even to countries to the south-east and those further west (Bangladesh, India) that depend on rivers that arise on the QTP (Figure 3b).

Alpine meadows, because of their sod-forming habit and their role in soil protection [23,24] are particularly important in the headwater regions on the QTP. The largest and most important of these is the so-called Three Rivers Regions (Sanjiangyuan). It covers an area of 152,300 km^2 and lies at an altitude between 3500 and 4600 m ASL. To protect the head waters of many important rivers (including five that are international rivers, there are plans to remove more than 200,000 herders and their livestock to new resettlement areas outside the Sanjiangyuan region. On one hand, there is the laudable attempt to conserve biodiversity and habitat [12,24] that is currently under threat from too many people and too many livestock competing for water and forage. The success or otherwise of the resettlement is the subject of considerable debate [25–30]. While on the other hand there is the sociocultural devastation as people, who until recently were semi nomadic and who (with their livestock) sought forage and water across the high plateau that is their spiritual home. Well-intentioned land management efforts, such as fencing, cause land fragmentation [31]. Restrictions on herder mobility cause concentration of livestock in critical 'refuge areas'. The changes in the length of the growing season (earlier 'green-up' and later senescence in the autumn) encourage extension of the grazing on 'summer pastures' to the detriment of native ungulates (and other fauna) that overwinter there [13,24,25]. See discussion on phenology in Section 4 below.

The landscape is characterized by expansive and flat grassland interspersed with both rounded and high mountains whose surface was weathered to such a degree that grassland is distributed everywhere except at the top above the snowline. The vegetation is dominated by grasses or 'grass like' species, for example, *Kobresia* spp.—a sedge.

According to [5] these alpine grasslands are predominantly in 'intact' natural condition in many areas. These grasslands though, are under threat of increasingly strong human activities such as overgrazing, cultivation, collection of fuel and medicinal plants, open pit mining, infrastructure development (roads, rail, transmission lines, rights of way, fencing) land fragmentation, as well as climate change [9,10,23]. Dominated by Lamaist pastoral cultures for millennia (Lamaist peoples are pastoralists grazing yaks, Tibetan sheep, goats, Bactrian camels and horses throughout the QTP rangelands. Most the local people practice Lamaism, a pastoral religion that combines Shamanism and Buddhism with a sprinkling of Dao (Taoist) symbolism). The rangelands in many parts are now almost completely devoid of woody plant species (the QTP is mostly naturally treeless except in the south-eastern river valleys). As a result, the degraded rangelands are subject to accelerated runoff, severe desertification and unpredictable climatic extremes due to widespread disruptions to heat–water cycle.

As Brierley [32] said " ... our present understanding ... is insufficient to ensure sustainable approaches to environmental management [on the QTP]. A key requirement for this to be achieved is effective understanding of the diversity of grassland types, their character/behavior, their pattern/distribution, their evolutionary trajectory, their linkages to other elements of landscapes, their vulnerability to disturbance (whether climate change or land use changes) and the ecological values of grassland ecosystems that we seek to protect". To this may be added changes in the policy environment as it relates to use rights, land tenure and changes in rural sociology of land users [33–37].

Harris [33] identified and assessed twelve factors implicated in grassland degradation. Half of these are biophysical in nature; the remaining six are human factors all influenced by wider socioeconomic processes, pointing to a need for better understanding of socio-ecological systems in the QTP as a basis for developing policy initiatives. In particular it is critical to investigate the rationale underlying 'traditional' grazing practices and ascertain the role of practices grazing (both good and bad) in grassland degradation. The common assumption that overgrazing is a key factor is questioned by some authors [12,24,25,33] yet this influences current policies such as sedentarization and new fencing regimes that appear to produce mixed ecological outcomes [36,37].

Until relatively recently, the long-term ecological implications of privatizing grassland and reducing spatial movement (including transhumance) had received little analysis despite early work by [24,36,38]. Arguments are mounting that flexible grazing practices are essential if there is to be sustainable grassland management [24,25,27,31].

3. Environmental Changes on Grasslands of the QTP under Global Change

An analysis of impacts of climate change on the grassland ecosystems of the Qinghai–Tibet Plateau (QTP) shows that the grasslands are sensitive to climate change and human disturbance [20,24]. This huge geographic region is also known as the "Third Pole". The ecosystems on the QTP play important roles in servicing the ecological environment and regional (SE Asian) socio-economic development and in the maintenance of biodiversity of plants and animals [39,40].

The grasslands of the QTP are the core of the water cycle, and their health directly affects the flux of water and water conservation capacity. In terms of glacier water, the glacier area is about 49,873 km^2 and ice reserves about 4561 km^3. The frozen soil area is 2.7×10^6 km^2, accounting for 46% of the total Qinghai–Tibetan Plateau land area. The groundwater in the QTP is the source of runoff water of many surrounding low altitude areas. The lake census showed that there are 32,843 lakes with a total area of 43,151 km^2, which makes up 1.4% of the total area of the Plateau. Around 96% of all lakes are small, with an area <1 km^2, while the 1204 large lakes (>1 km^2) account for a small percentage of the total area of lakes [41].

Climate change has already produced visible adverse effects on agriculture and livestock-raising sectors, manifested by increased instability in agricultural production, severe damage to crops and livestock breeding caused by drought and high temperature in some parts of the QTP. Moreover, under the background of climate change, herders have to adapt to the changes in terms of their production pattern as well as livelihood style. Therefore, understanding the effect of climate change on grassland production and response of herders to climate change is vital to improve grassland management on the QTP [1,42–44].

From 1951 to 2009, the ground surface temperature increased on average by 1.38 °C in China, the warming rates is 0.23 °C per 10 years, which is similar to the level of global warming. The warming on the QTP was greater than in other regions, especially in winter and spring. Most regions of QTP, including Xizang (Tibet) and Qinghai Province, have a greater warming rate compared to other regions. The climate in west and north QTP has changed from warmer-wetter to warmer-dryer, however, the climate in the east and south of the QTP has changed from warmer-dryer to warmer-wetter [38,41–43]. The precipitation on the QTP was generally rising in the 30 years ending 2012 (12.4 mm per 10 years) [42,45,46], in particular in the north of the QTP. The depth snow and the number of days with snow cover on the QTP increased from 1961 to 1990 and decreased from 1991 to 2005 [37,44,45].

IPCC [44] reported that the occurrence of extreme events is rising due to climate change. The snow disaster was also rising in recent years. Snow disaster or *dzud* (in Mongolian language and *kengschi* in Tibetan) is where deep snow, severe cold or other conditions make forage inaccessible or unavailable and leads to high livestock mortality. *Dzud* is a recurring natural event that limits the growth of livestock populations on the QTP, but it also causes loss of human life and livelihoods. In the *dzud* events of 1999–2002 and 2009–2010 the QTP lost 30% and 20% of the entire livestock flocks/herds, respectively, creating significant challenges for herders and rural communities who service the herders and their families. A herder's sole source of income can be wiped out by a *dzud*. On the QTP there are over one million herders and their families. In the 60 years ending in 2012, the snow disaster occurred 30 times in Qinghai Province, among them, severe snow disaster occurred 12 times and extreme snow disaster six times. From 1949 to 2002, the snow disaster occurred 80 times in Xizang (Tibet) and snow disasters that caused livestock mortalities in excess of two million head have occurred seven times [45]. The impact on people and their livelihoods is enormous [9,45,46].

4. Science and the Pastoral Management Interface on the QTP

The ongoing debate over spring vegetation phenological trends on the Tibetan Plateau, and the scientific disagreement over the role of climate change in driving these changes, illustrates the limitations of current scientific observations and knowledge of climate change and its impacts due to system complexity, heterogeneity and data scarcity (Klein et al. [47]. For example, NDVI-based phenology studies of Tibet show opposing trends (Chen et al. [48]; Shen, [49]; Shen et al. [50,51]; Wang and Chang, [52]; Yu et al., [53]; Zhang et al. [54]. Tibetan pastoralists perceived delays in the start of summer over multi-decade timescales, despite the shorter-term reversal of this trend revealed by NDVI measurements. The longer term NDVI trend toward delayed green-up corresponds with herders' local observations of shifts in seasonality, indicating that their long-term, qualitative perceptions support quantitative patterns deemed non-significant by Western scientific methods. In our experience, respondents who were engaged in herding as their primary livelihood consistently observed summers starting later, whereas those mostly engaged in non-herding livelihood activities were split, with those in the higher latitudes (areas with generally more mountainous terrain and less vegetative production) observing delayed summers, and those in the lower latitudes (areas with generally less mountainous terrain and higher vegetative production) split between observing no change and delayed summers. Klein et al. [47], and our own observations, suggest that policy interventions driven by scientific data derived from NVDI may run counter to pastoralists perceptions and ignore vital shifts in the availability of forage and water.

5. Conclusions

The alpine grasslands of the QTP have undergone major change in the past 70 years or so. Anthropogenic pressure has increased as populations of people and their livestock have more than doubled. In the past the alpine grasslands (the principal grazing lands) were under control of the local Buddhist temple, herders at that time followed directives about where and when to graze and mobility of livestock ensured that the herders had maximum access to forage and water [36,38,39]. In more recent decades there was phase of collectivization when government owned all the livestock and the land. Later in the 1980s, under the household contract responsibility system, ownership of livestock and grazing use rights to specified tracts of grassland passed to households. This created an anomaly in that livestock were privately owned and grazed on public land under a system of common use grazing [23]. Constraints on livestock inventories were very lax and livestock populations soared. Of late the government has tried to foster their national program to "Return grazing lands to grassland". Livestock numbers were restricted under this scheme and local animal husbandry and grassland monitoring bureaus have imposed grazing bans and erected fencing to regulate when and where livestock can graze. In situations where land degradation was severe, resettlement of herders (see above) and reduction of herd numbers has been implemented. About 220,000 herder families are to be moved from the Three Rivers region where the headwaters of the Yellow, Yangtze and Mekong Rivers are located. The grassland dynamics have changed a lot and now there is the increasing impact of greater climate variability as part of climate change [1,42,46].

The QTP is a vast and complex region characterized by harsh environmental conditions and mired in several policy gridlocks as government tries to meet its obligations under the various UN Conventions on biodiversity, climate and desertification as well as on human rights. There is a desire to 'close the gap' between the urbanized eastern part of China and the generally less well developed western regions (including the QTP) while maintaining social harmony as people are re-located in a bid to modernize the rural areas and deliver a wide range of social services (schools, clinics, pension schemes) and better infrastructure such as rural electrification, roads and trains, etc. Land use on the grasslands that have for millennia supported the hardy semi-nomadic herders, are now being re-organized and re-allocated. Despite these changes there is a vast area of alpine grassland that is a sink for carbon dioxide and habitat for a range of emblematic fauna including predators such as the snow leopard and numerous birds, rodent and fish that cannot be found elsewhere on the globe.

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