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Transformation of traditional pastoral livestock systems on the Tibetan steppe

Dennis P. Sheehy[1]
Daniel Miller[2*]
Douglas A. Johnson[3]

[1] International Centre for the Advancement of Pastoral Systems,
69086 Allen Canyon Road,
Wallowa,
Oregon, 97885,
USA
<dsheehy@wallowa.us>
[2] United States Agency for International Development (USAID),
1300 Pennsylvania Avenue, NW,
Washington, DC, 20036,
USA
<wildyakman@hotmail.com>
[3] United States Department of Agriculture (USDA),
Agricultural Research Service,
Forage and Range Research Lab,
Utah State University,
Logan,
Utah 84322-6300,
USA
<daj@cc.usu.edu>

* The views in this article are the author's and do not necessarily reflect those of the USAID.

Abstract

The rangelands of the Tibetan steppe cover an extensive area of Asia, which is comprised of a diversity of cold deserts, semiarid steppes, shrublands, alpine steppes, and moist alpine meadows. The climate of these rangelands is strongly continental, and most of the steppe is arid to semiarid. The Tibetan steppe is the source of many of the major rivers of Asia, and has a rich flora and fauna with many endemic species. This unique region has been traditionally used for transhumant grazing by yak, sheep, and goats. During the last 50 years, management of these rangelands has undergone major shifts from feudalism to collectivism to privatisation of livestock with individual grazing rights. Characteristics of the Tibetan steppe are described and discussed in relation to these management changes with emphasis on impacts on the land resources and herders' livelihoods.

Key words: rangelands, desert, steppe, Tibet, Central Asia, animal production, pastoralism, animal husbandry.

Résumé

Transformation des systèmes de production animale dans les steppes tibétaines

Les parcours de la steppe tibétaine occupent une vaste superficie en Asie centrale. Ils comprennent une variété de déserts froids, des steppes arbustives semi-arides et des steppes et des prairies humides alpines. Le climat régional est fortement continental. La plus grande partie de la région est couverte de steppes arides et semi-arides. La région est aussi la source de plusieurs fleuves asiatiques ; elle possède de riches flore et faune avec de nombreuses espèces endémiques. Cette région a été traditionnellement utilisée pour le pacage de troupeaux transhumants de yaks, de moutons et de chèvres. Au cours des 50 dernières années, la gestion de ces parcours a subi des changements considérables depuis le féodalisme jusqu'au collectivisme et la privatisation du bétail, avec des droits de pacage individuels. La caractérisation de la steppe tibétaine est décrite et discutée en relation avec les changements intervenus dans les méthodes de gestion. L'accent est mis sur l'impact des ressources foncières sur les moyens d'existence des éleveurs.

Mots clés : parcours, désert, steppe, Tibet, Asie centrale, production animale, pastoralisme, élevage.

Grazing animals and grazing-based livestock production systems remain an important component of the world's food supply [1]. Rangeland, which produces forage for grazing animals and is more suited for grazing rather than cultivation, occupies 40% of the 13.7 billion hectares comprising the earth's land surface. On the Tibetan steppe of Asia, almost all animal feed is obtained as forage by grazing livestock in traditional or modified pastoral livestock

production systems. Successful pastoral livestock production systems on the Tibetan steppe (similar to anywhere else in the world) must have:
– access to natural resources (forage, feed, shelter, water, etc.) needed to support livestock to produce off-take products;
– livestock that convert forage and other feeds into products (*i.e.*, meat, milk, fibre, manure, hides, etc.) that are directly consumable by the producer's family or that can be exchanged for other products or cash in the market-place;
– relatively few people dependent on natural resource use for their immediate livelihoods.

The Tibetan steppe with its strong continental climate is one of the most severe environments in the world where pastoral livestock production continues to be practised. Most rangelands on the Tibetan steppe are above 4,000m in elevation, and some herders maintain permanent camps at elevations as high as 5,100m. Despite this harsh climate, rangelands on the Tibetan steppe provide forage for an estimated 12million yak and 30 million sheep and goats that support the livelihoods of about 5 million pastoralists and agropastoralists. Through thousands of years, pastoral livestock production on the Tibetan steppe has continually involved decision-making by the pastoralists to mitigate risks and avert disasters. Risk imposed by environmental conditions is always a factor in meeting animal demand and livelihood needs in a pastoral system, and is an especially critical constraint on the Tibetan steppe. The needs of grazing animals to be productive and survive must continually be balanced with the availability of feed, water, and shelter across several different, but consecutively occurring, time-frames. The surest way of reducing risk in livestock production and ensuring sustainable livelihoods is to maintain flexibility of decision-making in animal production activities, mobility of adapted animals, and access to a variety of spatially and temporally distributed resources.

The traditional forage-based, extensively-managed pastoral livestock production systems that have existed for millennia on the Tibetan steppe, however, are showing declines in overall productivity. For example, about a third of the rangelands on the Qinghai-Tibetan Plateau are currently considered moderately to severely degraded [2]. In the Tibetan Autonomous Region, the percentage of degraded rangelands increased from 18 to 30% of total area between 1980 and 1990. Degradation is also a growing concern in Naqu Prefecture where degraded land makes up almost 40% of the total degraded rangeland in the entire Tibetan Autonomous Region [3]. Some *Kobresia*-dominated communities in alpine meadows of the Tibetan steppe have deteriorated to such a degree that most of the sedges and associated grasses have disappeared, leaving annual plant species and bare soil termed "black beach". Overgrazing and burrowing by pikas (*Ochotona* spp.) have been implicated as major causal factors of this degradation, although climate change and increasing aridity may also play a role [4]. This degradation calls into question the long-term sustainability of the Tibetan steppe under current use [2].

In this paper, the authors characterize the rangeland resources of the Tibetan steppe in China. They also highlight the major challenges that exist in trying to balance the needs for ensuring that this unique landscape continues to maintain critical water sources, provide habitat and forage for domestic livestock and wildlife, and maintain biological diversity. The hope is that this discussion will shed light on the ongoing decline in livestock productivity and ecological stability of natural resources on the Tibetan steppe, and assist in devising meaningful solutions to problems affecting the sustainability of households and production systems on the steppe. This paper draws heavily on information contained in studies by Sheehy [5] and Miller [6].

Geographical and topographical characteristics

General features

The Tibetan steppe encompasses a vast area in Asia located between about 26° 50′ and 39° 11′ North latitude *(figure 1)*. The majority of the steppe is contained within China, but it also extends into northwestern Bhutan, northern Nepal, and northwestern India. The Tibetan steppe stretches for almost 1,500 km from north to south and about 3,000 km from east to west, encompassing about a quarter of China's land area. The Himalayan Mountains demark the southern boundary of the steppe, while the Kunlun, Arjin, and Qilian Mountains delineate its northern boundary. The western boundary of the steppe is the juncture of the Himalayan, Karakoram, Kunlun, and Pamir Mountains. The eastern boundary of the steppe extends along the Qinghai highlands, western Gansu and Sichuan Provinces, and into northwestern Yunnan Province. More than 80% of the steppe is above 3,000m elevation, and about half is above 4,500m [7]. Many major rivers originate on the steppe including the Yellow, Yangtze, Mekong, Salween, Indus, Sutlej, Ganges, and Brahmaputra Rivers.

In China, the Tibetan steppe covers an area of about 165 million hectares, or 42% of China's grazing lands [8]. A provincial breakdown of the steppe area within China includes: 118.4 million hectares in the Tibetan Autonomous Region and Qinghai, 15 million hectares in the northern portion of the Kunlun Mountains in southern Xinjiang, 14 million hectares in western Sichuan, 5 million hectares in northwestern Yunnan, and 12 million hectares in western Gansu. Less than 1% of the steppe is cultivated with crops that include barley, wheat, peas, rape, and potatoes; however, cropping areas have expanded in recent decades, especially in the Qaidam Basin. In the eastern portion of the steppe, cropland is found in the lower valleys (below 3,300m), whereas in western Tibet cropping areas are found along the valley and tributaries of the Yarlung Tsangpo River (below 4,400m).

The Tibetan steppe has several distinct topographic regions determined by water drainage patterns and the parallel mountain ranges that divide it [7]. Much of the steppe consists of large lake basins surrounded by mountains with no outlets. Only the eastern and southern portions of the steppe have outlets to the ocean, with rivers originating in the Kunlun Mountains flowing north to the Taklimakan and Qaidam Deserts. Forests only occur on the eastern edge of the steppe in western Sichuan, northwestern Yunnan, southeastern Qinghai, eastern Tibet, and in some valleys on the northern slopes of the Himalayan Mountains.

Climate

The Tibetan steppe has a continental climate that is influenced by the southeastern monsoon in summer, and western air circulation patterns and high Mongol-Siberian air pressures in winter [9]. With the steppe sloping to the southeast, moisture from the southwest monsoons comes up gorges from the east and south. Summer precipitation decreases in a gradient from east to west and from south to north. The east of the steppe is humid, the south is semiarid, and far western Tibet is arid. The central steppe is subfrigid in a broad band from Gansu and Qinghai Provinces west through Tibet, and it is humid in the east and semiarid in the west. The northern portion of the steppe is frigid and arid [7]. For example, in Lhasa (3,658m), the average January temperature is -2°C and in July it is 15°C with an absolute minimum of -16°C with about 130 frost-free days. In Naqu Prefecture in northern Tibet (4,507m), the average temperature in

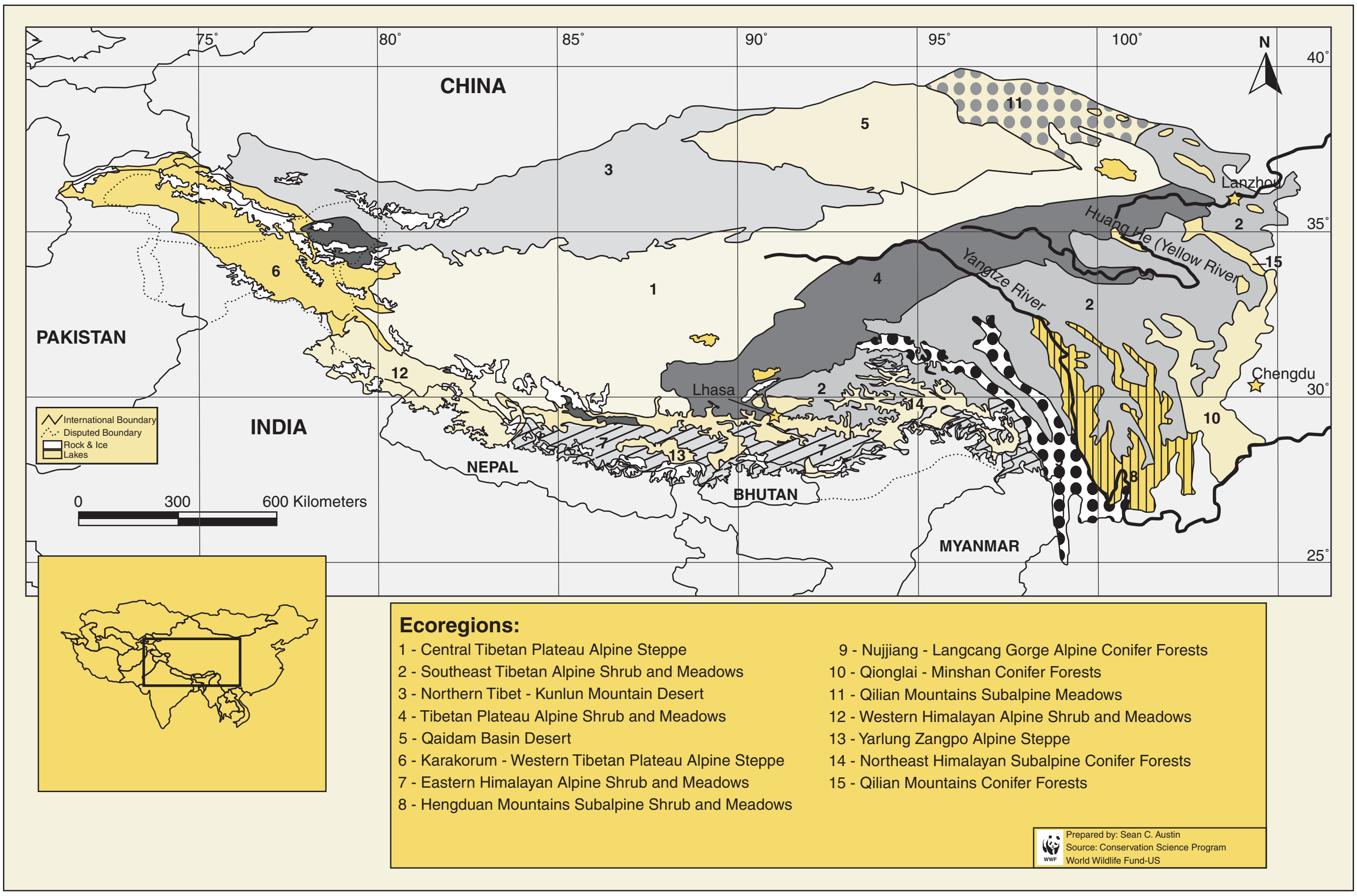

Figure 1. Major ecoregions of the Tibetan steppe (Source: World Wildlife Fund).

January is -14°C and in July it is 9°C with an absolute minimum of -41°C and only 20 frost-free days. The diurnal temperature range on the steppe varies, but is about 14 to 17°C [9] with rapid drops in temperature after sunset. The annual number of hours of sunshine averages 2,500 to 3,000 hours.

Annual precipitation varies from about 600mm in the eastern portion of the steppe to under 60mm in the western portion, mostly occurring as wet snow and hail during June to September. Most of the pastoral area receives less than 400mm of annual precipitation. Winters are generally dry, but heavy snows frequently occur and cover available forage, with accompanying low temperatures placing additional stress on livestock and wildlife. Much of the steppe (especially in the west) has strong winds with 100 to 150 days in a year having wind speeds more than 17m/sec.

Wildlife

The Tibetan steppe supports diverse mammalian faunas, and the northwest steppe contains a unique assemblage of large mammals [10]. Ungulates, a number of which are endemic, are of special significance [11]: Tibetan wild ass (*Equus kiang*), wild yak (*Bos grunniens*), Tibetan antelope *(Pantholops hodgsoni*), and Tibetan gazelle (*Procapra picticaudata*). The mountains provide habitat for blue sheep (*Pseudois nayaur*) and Tibetan argali (*Ovis ammon hodgsoni*). In the mountains of the eastern steppe, where forests mix with grasslands, musk deer (*Moschus sifanicus*), MacNeil's deer (*Cervus elaphus macneilli*), white-lipped deer (*Cervus albirostris*), roe deer (*Capreolus capreolus bedfordi*), and takin (*Budorcas taxicolor*) are found [12]. In southern Tibet, scattered populations of Tibet red deer (*Cervus elaphus wallichi)* are still found. Przewalski's gazelle (*Procapra przewalskii*) occur in the vicinity of Qinghai Lake, and goitered gazelle (*Gazella subgutturosa*) are found on the northern edge of the steppe. Predators such as brown bear (*Ursus arctos*), wolf (*Canis lupus*), snow leopard (*Uncia uncia*), lynx (*Felis lynx*), Tibetan steppe fox (*Vulpes ferrilata*), and red fox (*Vulpes vulpes*) are also present, and smaller mammals such as marmot (*Marmota bobak*) and pika (*Ochotona* spp.) are common [13].

In Tibet alone, over 500 bird species have been recorded [14] including predatory birds such as the steppe eagle (*Aquila nipalensis*), upland buzzard (*Buteo hemilasius*), saker falcon (*Falco cherrug*), goshawk (*Accipiter gentilis*), black kite (*Milvus migrans*), and small owls (*Athene noctua*). In addition, several species of snow finches (*Montifringilla* spp.), pheasants (*Crossoptilon* spp., *Tetraogallus* spp.), and Tibetan sandgrouse (*Syrrhaptes tibetanus*) are found. Waterfowl such as the black-necked crane (*Grus nigricollis*), bar-headed goose (*Anser indicus*), and ruddy shelduck (*Tadorna ferruginea*) are also present.

Floristic features of the Tibetan steppe

General characteristics

Central Asia can be divided into the Mongolian and Tibetan floristic provinces; the latter includes the entire Tibetan steppe except the Qaidam Basin, Pamir Mountains, and southwestern Xinjiang. The Qaidam Basin is geographically part of Tibet,

but its vegetation has more affinity to the Mongolian province [15]. The Tibetan floristic province can be divided into four regions:
1. Nan Shan and Chamdo in the northeast;
2. Deep river valleys in the southeast;
3. Deep longitudinal valley of the Yarlung Tsangpo River in the south;
4. Vast High Tibetan or Chang Tang.

Several floras converge on the steppe including those of Central Asia, East Asia, and the Himalayan Mountains. In Tibet, more than 2,000 plant species have been identified [16], mainly in the families Compositae (330 species), Gramineae (277), Leguminosae (123), Rosaceae (102), Cyperaceae (102), and Polygonaceae (63). The vegetation of the Tibetan steppe and its floral elements differ strongly from the subtropical mountain forest vegetation of southeastern Tibet and adjoining regions [17]. Endemics comprise about 1,200 of all Tibetan species.

Kingdom-Ward [18] identified six subregions within the Tibetan steppe:
1. Interior plateau;
2. Outer plateau;
3. Rainy gorge region;
4. Arid gorge region;
5. Qaidam Basin;
6. Chinese Tibet (or the northeastern part of the steppe).

Scientific investigations of the resources of the Tibetan steppe were conducted by the Qinghai and Gansu Integrated Survey Team of the Chinese Academy of Sciences in 1963 and the Xizang Integrated Survey Team of the Chinese Academy of Sciences in 1966.

Chang [17] divided the vegetation on the Tibetan steppe into five major regions:
1. High-cold or alpine meadow of eastern Tibet;
2. Xeric shrubland and steppe along the valleys of the Yarlung Tsangpo (Brahmaputra River) and Indus River in southern Tibet;
3. High-cold or alpine steppe in northern Tibet;
4. High-cold desert in northwestern Tibet;
5. Temperate desert in southwestern Tibet.

Schaller [7] followed Chang's classification, but added a sixth region, the Qaidam Basin.

Vegetation types

Within each region, there is a diverse assortment of plant communities that vary in species composition and structure based on factors such as elevation, aspect, drainage, and precipitation [19]. For example, Chang and Gauch [20] described 26 plant communities in western Tibet, and Achuff and Petocz [21] identified 18 communities in the Arjin Shan Region of Xinjiang on the northern edge of the Tibetan steppe. Vegetation on the plains has a broad horizontal zonation and on the mountain slopes has a relatively narrow vertical zonation, both based on precipitation and elevation. China's rangeland resources on the Tibetan steppe were surveyed and mapped in the 1980s and classified into 17 vegetation types based on climatic zones, humidity index, vegetation, and importance to the livestock industry [22, 23]. These vegetation types, their aerial extent, and percentage of the total area of the Tibetan steppe are presented in *table 1*. Others classified rangelands of the Tibetan Autonomous Region into 12 different types [16, 26, 27]. These 12 vegetation types and associated dominant species are presented in *table 2*.

Table I. Vegetation types of the Tibetan steppe (adapted from [24, 25]).

Vegetation type	Area (1,000 ha)	Percent of total area (%)
Temperate meadow-steppe	210	0.16
Temperate steppe	3,833	2.92
Temperate desert-steppe	968	0.74
Alpine meadow-steppe	5,626	4.28
Alpine steppe	37,762	28.75
Alpine desert-steppe	8,679	6.61
Temperate steppe-desert	107	0.08
Temperate desert	2,084	1.59
Alpine desert	5,967	4.54
Tropical tussock	9	--
Tropical shrub tussock	28	0.02
Temperate tussock	1	--
Temperate shrub tussock	140	0.10
Lowland meadow	1,168	0.88
Temperate mountain meadow	6,067	4.61
Alpine meadow	58,652	44.64
Marsh	21	0.01
Total	**131,322**	**99.93**

Characteristics of four major vegetation types

Vegetative attributes of the Tibetan steppe vary greatly depending on the particular combinations of topography, soils, precipitation, and grazing history of the area. Because of space limitations, only the four major vegetation types, comprising nearly 85% of the Tibetan steppe will be discussed here.

• Alpine meadow type

The alpine meadow type makes up about 45% of the Tibetan steppe and is found on valley floors and mountain slopes in the eastern part of the steppe from about 3,500 to 4,500m elevation with an annual precipitation of more than 400mm. This type is widespread in southwestern Gansu, western Sichuan, and southeastern and southern Qinghai and extends into Tibet to the longitude of Lhasa. Further west on the steppe, the alpine meadow type occurs mainly in riparian areas and areas receiving melt-water runoff [7, 28]. The alpine meadow soil averages 20 to 40cm deep and is rich in organic matter. The surface layer is a substantial, resilient sod [9]. Ni [24] concluded that high carbon storage in the thick sod layer of alpine meadows may play an important role in the global carbon cycle.

Alpine meadow is dominated by sedges of the genera *Kobresia* [9]; dominant species are *Kobresia pygmaea, K. humilis, K. capillifolia, K. setschwanensis, K. schoenoides,* and *K. littledalei*. *Carex atrofusca, Polygonum viviparum,* and *Polygonum macrophyllum* are the subdominant species in the alpine meadow, and numerous forbs are also found including species in the genera: *Leontopodium, Anemone, Anaphalis, Polygonum, Pedicularis, Rheum, Androsace, Gentiana, Ranunculus, Aconitum, Astragalus, Oxytropis, Primula,* and *Potentilla*. Grasses include: *Elymus nutans, Roegneria nutans, Koeleria litwinowii, Helictotrichon tibeticum, Brachypodium sylvaticum, Stipa aliena, Festuca rubra, Festuca ovina,* and *Deschampsia caespitosa.* Large areas of productive pasture in alpine meadow are dominated by *Elymus nutans*, especially in northwestern Sichuan, southwestern Gansu, and eastern Qinghai. In swampy depressions in the alpine meadow, hummock vegetation occurs, which is dominated by *Kobresia* spp. (30-cm tall *K. royleana, K. schoenoides*). Shrub communities of *Salix* spp., *Caragana jubata, Potentilla fruticosa,* and *Rhododendron*

Table II. Major vegetation types and plant communities in the Tibetan Autonomous Region (adapted from [16, 26]).

Vegetation type	**Dominant plant species**
Alpine meadow	*Kobresia* spp.
Alpine shrub meadow	*Rhododendron-Kobresia*
Sub-alpine shrub meadow	*Sabina-K. bellardii*
	Picea –K. bellardii
	Quercus semicarpifolia – K. bellardii
	Salix/Spiraea/Berberis
Mountain shrub steppe	*Sophora viciifolia – Pennisetum flaccidum*
	Sophora viciifolia – Orinus thoroldii
Mountain steppe	*Artemisia stracheyi – K. bellardii*
	Artemisia stracheyi – Stipa spp.
	Artemisia stracheyi – Orinus thoroldii
	Orinus thoroldii
	Achnatherum hookeri
	Stipa bungeana – Pennisetum flaccidum
Alpine steppe	*Stipa purpurea*
	Stipa purpurea – Kobresia spp.
	Stipa purpurea – Caragana versicolar
	Stipa purpurea – Festuca ovina
Mountain desert steppe	*Stipa glareosa*
	Stipa glareosa – Ceratoides latens
	Caragana versicolar – Stipa glareosa
	Caragana versicolar – Ceratoides latens
	Ajania fruticulosa – Stipa glareosa
Mountain desert	*Ceratoides latens – Stipa* spp.
	Ceratoides latens
Alpine desert	*Carex moorcroftii*
	Ceratoides compacta – Carex moorcroftii
	Ceratoides compacta
Alpine cushion vegetation	
Lake basin and valley meadow grassland	
Woodland meadow	

spp. are common on northern aspects in alpine meadow.

Most Tibetan pastoralists and their stock are located in the alpine meadow region, where livestock densities can be high. For example, in eastern Qinghai Province stocking rates are 28 to 70 animals/km^2. Heavy grazing and trampling along with solifluction have disturbed the sod layer, causing extensive rangeland degradation in some areas [7].

• Alpine steppe type

The alpine steppe comprises nearly 29% of the Tibetan steppe and is found between elevations of 3,500 and 4,600 m in the central and western portions of the steppe. Unlike the alpine meadow, the alpine steppe does not have a sod layer, and the soil is often gravel and coarse sandy loam. The alpine steppe is a variant of the temperate steppe type under the cold conditions of the Tibetan steppe [9]. Grasses (*Stipa purpurea, S. subsessiliflora*) dominate this type and often grow in association with cushion plants (*Androsace tapete, Arenaria musciformis, Oxytropis microphylla*). Associated species are mainly xeric and meso-xeric grasses: *Poa alpina, Poa crymophila, Poa dolichachyra, Roegneria nutans, Roegneria thoroldiana, Agropyron cristatum, Stipa aliena, Orinus thoroldii, Calamagrostis* spp., *Festuca rubra*, *Kobresia* spp., and *Carex moorcroftii*. Shrubs include: *Potentilla fruticosa, Ajana* spp., *Artemisia* spp., and *Ceratoides compacta.* Forbs include: *Potentilla bifurca*, *Dracocephalum heterophyllum, Heteropappus altaicus, Leontopodium* spp., *Pedicularis* spp., *Allium* spp., *Oxytropis* spp., and *Astragalus* spp.

Along the drainage of the Yarlung Tsangpo River in the rain shadow of the Himalayan Mountains between 3,500 to 4,000m elevation on valley floors and lower mountain slopes, the dominant vegetation consists of xeric grasses such as *Aristida triseta, Stipa bungeana, Pennisetum flaccidum, Elymus nutans*, and *Orinus thoroldii*. Shrubs such as *Artemisia webbiana, Berberis* spp, *Sophora moorcroftiana, Sophora viciifolia, Lonicera spinosa, Leptodermis sauranja,* and *Ceratostigma griffithii* are often mixed with grasses, or occur as distinct communities. *Juniperus* shrub communities are found on the upper slopes. Because this central valley region was settled by farmers, most of the area has been subjected to heavy, continuous grazing for centuries, with resulting overgrazing and degradation [29, 30]. Desertification and moving sand dunes are serious problems in many areas in the Yarlung Tsangpo Valley.

In the alpine steppe, plant canopy cover varies from 10 to 30%, and productivity is often less than 300 kg dry matter/ha. Within the alpine steppe, swampy depressions fed by snow and glacial streams are dominated by *Kobresia* spp. These areas are key grazing areas during early spring because plants there initiate growth earlier than surrounding vegetation, which depends on summer precipitation for growth [31]. The alpine steppe is important for pastoral production [32], and most is still in quite good ecological condition, although overgrazing is common near settlements. Schaller [7] estimated livestock density in the alpine steppe in northern Tibet at 8.7 animals/km^2 (calculated as: sheep 5.71/km^2, goats 2.60/km^2, yak 0.36 km/^{2}, and horses 0.07/km^2).

• Alpine desert-steppe type

The alpine desert steppe, which extends from northern Tibet into southern Xinjiang Autonomous Region, is a bleak, arid landscape with large areas nearly devoid of vegetation [7]. This type makes up about 6% of the total grassland of the steppe. Vegetation is similar to the alpine steppe, but plant cover is less. *Ceratoides compacta* (dwarf shrub) and *Carex moorcroftii* (sedge) are the dominant plants on the alpine desert steppe. Few livestock are found in this cold-high desert, and even wild ungulates are limited in number [33].

• Temperate mountain-meadow type

The temperate mountain meadow is found mainly in western Sichuan, southeastern Qinghai, and eastern Tibet and often occurs within spruce (*Picea* spp.) forests between elevations of 3,330 to 4,200m. This type makes up 4.6% of the Tibetan steppe. Important grass genera include: *Festuca, Ptilagrostis, Poa, Helictotrichon, Agrostis, Bromus, Elymus, Roegneria,* and *Deyeuxia*. Common forb genera include: *Polygonum, Aconitum, Delphinium, Rheum,* and *Ligularia*. Shrubs include: *Rhododendron, Philadelphus, Sorbus, Salix, Spiraea, Prunus,* and *Lonicera*.

Table III. Annual dry matter production and carrying capacity for different rangeland vegetation types in Hainan Prefecture in Qinghai Province [34].

Pasture type	Dry matter (kg/ha)	Carrying capacity (ha/SU/yr)
Alpine meadow	934	0.78
Temperate meadow-steppe	623	1.17
Alpine steppe	594	1.23
Temperate desert steppe	345	2.11
Temperate desert	228	3.19
Lowland meadow	1,341	0.54

SU : Sheep unit.

Rangeland productivity

Standing crop on the steppe varies considerably (*table 3*). Alpine meadows are some of the most productive vegetation types, where average annual dry matter production can reach 1,000 kg/ha. Productivity of deserts, of course, is low and averages only 100 to 200 kg dry matter/ha. In Aksai County in Gansu Province, Harris and Bedunah [35] found that average standing crop varied from 115 kg dry matter/ha in desert shrub to 790 kg dry matter/ha in desert subirrigated meadows (*table 4*).

Forage quality

On most of the Tibetan steppe the only source of nutrients for livestock, except for small amounts of hay and purchased concentrates, is from natural forage. As a result, understanding the temporal and spatial dynamics of plant production in regard to plant and animal needs as well as demand functions in the livestock production system is important [5]. High protein and nutrient content was observed for all plant growth forms at the end of the growing season in an alpine meadow in Guolou Prefecture in Qinghai Province (*table 5*). The total amount of nutrients available to livestock and wildlife in autumn and winter was much higher than found in many other grazing ecosystems. This has important implications for livestock production:

– sufficient nutrients remain available on the Tibetan steppe to maintain livestock through normal periods when forage is not growing;

– degraded vegetation had relatively high nutrients;

– capacity of Tibetan rangelands to support livestock needs to be evaluated both from a nutrient content and consumable biomass basis [5].

Grazing on the Tibetan steppe

Historical aspects of Tibetan pastoralism

Pastoralists have probably been raising stock on the Tibetan steppe for about 4,000 years [36, 37]. As early as the Hsia Dynasty (2205-1766 BC), nomadic Qiang were making fine woven woollen material in the Kunlun Mountains. During the Shang Dynasty (1766-1027 BC), nomads in eastern Tibet were renowned for their horses. The development of Tibetan pastoralism was shaped by nomads from Central Asia who brought sheep, goats, and horses. Most herders on the Tibetan steppe are Tibetan, but there are small groups of Mongols and Kazakhs in Qinghai Province. Population density across much of the steppe is less than 2 persons per km^2 [30]. For a distance of almost 3,000 km, Tibetan is spoken and has been a written language for about 1,300 years. In recent decades, pastoralists across most of the steppe have built houses and livestock shelters on traditional winter-spring pastures where they spend up to 6 to 7 months of the year. The vast majority of herders has been "settled" for some time, but graze their livestock in a transhumant manner [38].

Tibetan pastoralism has evolved through long-term adaptation and persistence by herders [39–42]. Pastoralists traditionally kept a mix of livestock species and classes, and used a mosaic of grazing sites that exploited seasonal and annual variability. Herders bartered products for grain and supplies, and quite elaborate trade linkages developed between pastoral and agricultural areas. Tibetan pastoralism is distinct ecologically from that of other semiarid regions, except Mongolia [43], because it is separated from agricultural areas by temperature, not aridity [39, 44–46]. The yak (*Bos grunniens*), which is well adapted to the cold Tibetan steppe, also distinguishes Tibetan pastoralism [47, 48]. The domesticated yak enabled nomads to effectively harvest vegetation types on the harsh Tibetan steppe [49].

Land tenure

Before 1949, a feudal "estate" system of land tenure existed with land controlled by religious and aristocratic elites [45]. Wealthy, powerful monasteries controlled huge fiefdoms with numerous pastoral estates and thousands of subjects. Herders were bound to an estate and not free to leave it, but owned their animals and managed them as they wished. Herders paid taxes and worked for their lord. Traditionally, pastoral estates were divided into numerous pastures, with borders recorded in a register book [45]. Households were allocated grazing land according to the number of livestock owned, including multiple pastures for use at different seasons. The system balanced rangeland resources and livestock by reallocating pastures among families according to a census conducted every three years. Herders whose stock numbers increased during the previous three years were allocated more grazing land, whereas those with declining stock numbers lost land. The aim of the system was to maintain a specified number of livestock on each pasture [45].

In many areas, herders were organized as a confederacy of separate kin-based groups. These groups were divided into "encampments" of five to ten households, and each encampment had rights to a set

Table IV. Standing crop (kg/dry matter/ha) for various vegetation types in Aksai County in Gansu Province at an elevation of 3,100 to 4,400m [35].

Vegetation type	Standing crop	Dominant species
Desert shrub	115	*Sympegma regelii, Reaumuria soongarica*
Desert steppe	167	*Oxytropis aciphylla, Leymus paboanus, Stipa glareosa*
Alpine desert shrub	141	*Ceratoides compacta, Stipa glareosa*
Alpine steppe	245	*Stipa purpurea, Poa* spp., *Festuca* spp., *Carex moorcroftii*
Desert subirrigated meadows	790	*Carex* spp., *Achnatherum splendens*
Meadows and sandy grasslands	423	*Carex* spp., *Leymus paboanus, Stipa* spp., *Kobresia* spp.

Table V. Crude protein (CP) and total digestible nutrients (TDN) for vegetation of the second livestock cooperative in Guolou Prefecture in Qinghai Province as a percentage of dry matter [5].

Season	Grasses		Forbs		Shrubs	
	CP	TDN	CP	TDN	CP	TDN
Late June	16.1	79.5	16.6	85.4	19.1	83.1
Late July	15.0	78.2	15.0	83.9	17.8	82.6
Mid-September	10.5	79.6	10.5	83.8	10.0	80.7

of seasonal grazing areas within the wider "tribal" territory. Natural features such as ridges and streams [50] marked boundaries. Herders had heritable grazing rights within a group territory [51]. In areas outside the control of large pastoral estates, grazing rights were very insecure and depended on force [50]. While the rights of tribes to certain tracts of land were fixed (unless and until other tribes took them by force), rights of encampments were more fluid. The camping sites and grazing grounds of the various groups could be changed from one part of the tribal territory to another at the discretion of tribal leaders and in response to changing needs of the encampment [50]. In the Golog Region of the northeastern steppe, winter camps had a sense of "ownership" by specific encampment groups. Households in the encampment had "individual and exclusive rights over certain hayfields" near winter sites [52].

Since 1949, the Chinese Government has induced profound changes in land tenure and social organization of pastoral communities. In the 1950s, when land reform was being implemented throughout China, grazing lands were nationalized, and aristocratic and monastic lords lost their estates. However, State ownership of grazing land was not incorporated into law until 1982 [53]. When communes were established in the late 1950s and 1960s, ownership was vested in production teams, which came to regard rangeland as collective property. Thus, a *de facto* situation emerged with State- and collectively-owned pastures. All livestock were the property of the communes with herders holding shares in the communes' livestock. In the commune era, however, mobile pastoralism continued, and no attempt was made to reduce the geographic scope of livestock production.

Decollectivisation of the agricultural sector in China was authorized in 1978. Reforms began in agricultural areas of eastern China, where communes and State farms were dismantled, and their lands were redistributed under the family-based Household Contract Responsibility System [54]. In agricultural areas, farmers could lease land, and land-use rights could be subcontracted or inherited. The contract system became the orthodox form of land tenure for agriculture and was applied to grasslands with the promulgation of the Grassland Law in 1985 [53]. This Law stated that the user rights of State or collective land could be leased "long-term" to households, although in practice lease periods typically extended to 30 years and in special circumstances to 50 years. In most of the pastoral area of Qinghai, southwest Gansu, and northwestern Sichuan Provinces, many herders have settled and fenced pastures contracted to them. The allocation of rangeland is at the community and small-group level, similar to the pre-commune era [41].

Harsh climate of Tibetan steppe and pastoral dynamics

The strong continental climate and periodic weather perturbations that occur on the Tibetan steppe in the form of sudden, brutal snowstorms add to the complexity and dynamic nature of the steppe [55, 56]. Snowstorms are a fundamental feature of climate on the Tibetan steppe and probably serve as an important regulatory mechanism in the pastoral system. Serious losses occur as a result of heavy snowfalls and severe cold weather [7, 28, 46, 51, 55]. For example, from 1955 to 1990 six severe winters with heavy snow were reported resulting in 20 to 30% livestock losses with each winter. Similarly, the winter of 1995-1996 was severe in many parts of the steppe with 33% livestock loss in Yushu Prefecture of Qinghai Province. In Naqu Prefecture, 20% of the pastoral population of 340,000 lived in poverty prior to the severe 1997-1998 winter, whereas the poverty percentage increased to 40% the following year. Losses due to unseasonably cold weather during summer are also common. For example, Goldstein and Beall [45] found that after five days of snow in the summer of 1986, one herding area lost 30% of its livestock. Herding on the Tibetan steppe has always been a high-risk enterprise, and pastoralists have adopted strategies that minimize risk and make the best use of grazing resources [45, 46].

Livestock management

Pastoral practices are similar across the steppe, although the composition and size of herds differ. Herders keep herds of yak, yak-cattle crosses, sheep, goats, and horses. Yaks are preferred at extreme altitudes, in snow, and for riding in rough country [43]. Their dung is also an important fuel. Sheep and goats are most important in the west, and are milked there. In the east, yaks supply all the nomads' milk needs. Mutton is the preferred meat, whereas goats yield cashmere, meat, and milk. Horses are used primarily for riding, but are also used as pack animals. Mares are not milked, and Tibetans do not eat horsemeat. Since disbanding of the communes, livestock are owned by individual families who are responsible for their livestock, and the processing and marketing of livestock products. The proportion of livestock species and the size of Tibetan herds differ according to specific rangelands and the suitability of the landscape for different animals. Herd compositions within a geographic area can also differ with Government policies, herders' skills and livestock preferences, and availability of labour.

Traditionally, extensive grazing management was adapted to the local conditions, and livestock were regularly moved between pastures to maintain rangeland condition and animal productivity. Grazing lands were divided into seasonal pastures and grazed according to managerial and production objectives. Pastoralists' movements were well prescribed by complex social organizations and were highly regulated. Mobility is still vital for most herders, although with escalating settlement, livestock mobility is being curtailed. The traditional system was designed around the seasonal movement of livestock with herds using forage in summer and reserved forage areas for autumn and early winter to prepare animals for the long winter. Today's survival of numerous, prosperous groups of Tibetan pastoralists testifies to their extraordinary indigenous knowledge, resourcefulness, and animal husbandry skills. During the last few decades, traditional livestock and grazing management systems have been altered, and they are continuing to change today.

Transformation of traditional pastoral production systems

The profound changes of land tenure that occurred during recent decades transformed traditional land use, altered grazing land conditions, and disrupted the lives of pastoralists. Often these political, social, economic, and ecological transformations altered previously stable relationships between pastoralists and grazing lands. For example, in the mid-1980s, winter grazing lands were allocated to households, and winter pastures were fenced. This began in areas near Qinghai Lake, but quickly spread to herding areas in Gansu and Sichuan Provinces. Exclusive rights to specific grazing lands for herding households can now be inherited, but not bought or sold. There is no mechanism yet in place for the readjustment of grazing land to individual families when livestock numbers fluctuate.

In the Tibetan Autonomous Region, rangelands are being allocated to groups of herders rather than to households. Explanation for the difference in the privatisation process in Tibet is that rangelands there are not as productive and expenses for fencing individual properties would be prohibitive. A recent development on the steppe is that summer grazing lands are also being privatised and fenced, except again in the Tibetan Autonomous Region where they are being allocated to groups instead of households. These activities are being undertaken on a large scale in almost all pastoral areas of Qinghai, Gansu, and Sichuan Provinces with substantial Government and donor investment. Great attention is being given to settling of herders, even in Tibet.

The heavy livestock losses experienced on the Tibetan steppe in recent years has convinced many authorities that transhumant pastoralism needs to be restructured. Programs to settle herders, privatise and fence pasture, and develop fodder for winter are seen as ways to prevent losses in severe winters and control what is perceived as widespread pasture degradation. While some of these interventions have merit, such as the growing of annual forage for hay, the long-term ecological implications of privatising rangeland and reducing the spatial movement of herds have received little analysis [56]. The socioeconomic and land-tenure ramifications of herders being settled on defined properties have also not been examined. Foggin and Smith [57] suggested that summer-autumn pastures may be unintentionally degraded further as artificially high winter livestock populations are forced to graze on reduced areas of summer-autumn pasture.

Discussion

Pastoral livestock production systems on the Tibetan steppe exist within the larger context of pastoral ecosystems in a cold temperate zone. The perception of how particular ecological systems operate determines the approaches that are advocated in attempting to modify or manipulate ecosystems to improve sustainability of ecosystem use [58]. Until recently, ecosystems occupied by pastoralists were generally thought to function as "equilibrium systems", which were regulated by animal density-dependent feedback controls that pastoralists often override to the detriment of themselves and the ecosystems in which they operate. Today it is thought that many ecosystems occupied by pastoral production systems are "non-equilibrium systems", which are controlled by external mechanisms and are not subject to feedback control mechanisms from within the system. However, Tibetan steppe ecosystems dominated by alpine meadow, alpine steppe, and temperate mountain meadow vegetation types appear to be more equilibrium than non-equilibrium systems, as evidenced by the impact of pika and overgrazing in moving these systems to a different "steady state," (*i.e., Kobresia* turf communities degrading to black beach). Efforts to re-establish natural communities in these vegetation types have generally been unsuccessful. As stocking rate increases, either through continued degradation of ecosystem productivity or by increasing animal numbers, restoring ecosystems of the Tibetan steppe to a higher productive state will have even a lower probability of success.

It should be noted that traditional livestock use of the Tibetan steppe has been similar to a naturally functioning wild herbivore system. One difference between a wild herbivore system and steppe livestock production systems is the layer of control and management exerted by the herder on domesticated herbivores. Control and management are necessary to ensure human livelihoods on the steppe and were instituted in response to current or future impending environmental constraints to mitigate the potential negative impacts on livestock directly and on the pastoralist's livelihood indirectly. Despite the application of control and management interventions, the system is still subject to the same set of environmental constraints as wild herbivores. Although long-distance migrations that mimicked naturally functioning wild herbivore movements between seasonal pastures continue on the Tibetan steppe, this important factor of production and household sustainability is declining rapidly as herders become more sedentary.

Herding families are becoming settled not only as a result of Government policies designed to promote privatisation of production resources, but also because overpopulation and overuse of natural resources are causing fundamental social and economic changes among the herding households themselves. Among these factors, the decline of natural resources capacity to support animal production is the major stress on cultural and social identity of Tibetan animal production households.

With attempts to transform pastoral livestock production towards a market economy, increased livestock off-take has often been the goal. This has been promoted through privatisation of herds and land, settling of herders, production of rainfed forage, and introduction of less mobile, intensive grazing management. While many of these interventions have improved the delivery of social services, in many instances they have conflicted with the goal of maintaining grassland health and stability because they limited the critical factor of mobility [8, 59]. Movements between seasonal pastures are being reduced or eliminated, herd composition is being restructured along commercial lines, and herders are being compelled to become livestock farmers. The environment and the pastoral cultures are under threat where mobility has been eliminated or substantially reduced [60, 61].

There is growing appreciation of the complexity and ecological and economic efficacy of traditional pastoralism [62]. When analysing transhumant pastoral production on the Tibetan steppe, one is faced with problems of two production strategies. First, there is the strategy involving the traditional indigenous system, which can be seen as an evolutionary response to a complex suite of environmental pressures. This strategy represents a pattern of survival that has evolved through time and continues to exist today. Second, there is the new strategy for survival that focuses on balancing economic and ecological sustainability, based on technical rationale brought in from the outside. However, this latter strategy has not been fully accepted into the existing socioeconomic structure on the steppe and has not been subjected to the test of time. Combining traditional pastoral strategies with sustainable strategies in today's context will critically hinge on the successful incorporation of indigenous knowledge from pastoralists. New production systems on the steppe will only be successful when pastoralists' needs and desires are heard, and their indigenous knowledge incorporated into the design of new strategies [63, 64]. Herders must be empowered to manage their own development.

Conclusion

Rangeland ecosystems on the Tibetan steppe are complex, not only in the ways that physical forces shape the landscape, but also in the ways that socioeconomic, political, and institutional forces interact and impact the people who use the rangeland resources. The people who use the steppe rangelands live in a multifaceted environment of physical, financial, social, educational, institutional, and regulatory forces that influence their actions. Sustainable pastoral development requires an examination of all the forces that affect the pastoralists who use the rangelands. However, despite the extent and importance of rangelands on the Tibetan steppe, rangeland ecosystem dynamics there are still poorly understood and sound scientific data on ecological processes on the steppe rangelands are limited. Many questions concerning how rangeland vegetation on the steppe functions, the effect of both domestic and wild herbivores on pastoral systems, and the socioeconomic dimensions of pastoral production on the steppe remain unanswered. This lack of information limits the proper management and sustainable development of steppe rangelands. A better understanding of current nomadic pastoral practices and how they are changing and adapting to the influences of modernization is critically needed.

The Tibetan steppe and the people who live there are in transition from a known past to an unknown future. Drastic political, economic, and social changes have occurred on the Tibetan steppe during the last half-century. Despite these changes, livestock production on the Tibetan steppe still critically depends on standing crop of forage to support livestock production activities throughout annual production cycles. Thus, animal access to standing crop is a key element of forage-based livestock production systems on the steppe. However, ensuring livestock access to standing crop of forage is becoming increasingly difficult as deteriorating rangeland conditions decrease amount and quality of standing crop. Livestock production by households throughout the Tibetan steppe is increasing in complexity as the production system is forced to respond to new paradigms. An incomplete understanding of how to respond to new paradigms is affecting interactions between humans, livestock, and production resources throughout the livestock production system. If livestock production is to remain an economically viable and environmentally sustainable enterprise on the Tibetan steppe, an accurate and realistic understanding of livestock production interactions on the steppe is critical in effectively adapting livestock production to new paradigms.

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