Impacts of Agropastoralism on the Timberline Ecotone in the Hengduan Ranges of the Eastern Tibetan Plateau

Yi Shaoliang[1,2*], and Wu Ning[2]

[1] Aga Khan Foundation, Afghanistan

[2] International Centre for Integrated Mountain Development, GPO Box 3226, Kathmandu, Nepal

* syi@icimod.org

The spatial patterns of treelines and timberlines in the eastern Tibetan Plateau show marked regional and slope-wise variation. Within the region, the treeline elevation increases from the southern and peripheral areas to the northwest. Under natural conditions, timberlines and treelines occur in pairs with an altitudinal difference ranging between 15 and 300 m and a clear timberline ecotone in between. However, in places where human activities are frequent, the forests often end abruptly without a treeline or timberline ecotone. In such areas, the timberlines are usually higher on the shady (northern or northeastern) slopes than on the sunny (southern or southwestern) slopes. The difference ranges from 20-30 m in some places to 100-300 m in other places.

Major timberline and treeline species in the region include Abies spp., Picea spp., Larix spp., Sabina spp., and Quercus spp., with clear differences across the region and among slope aspects. Quercus spp. and Sabina spp. are usually found on sunny slopes or mountain ridges; Abies spp. are the main species in the peripheral parts of the Plateau, where climates are more humid, regardless of slope; and Picea spp. are the main species on both sunny and shady slopes further into the interior of the Plateau.Larix spp. usually occurs are often seen on sunny slopes or mountain ridges above the timberline.

Migratory pastoralism is one of the major ways in which local societies interact with the timberline ecosystem in the region. Every year, herders and their livestock spend about 60-120 days in the forests and 60-100 days on the high pastures during the migration cycle. Grazing affects the alpine timberline ecotone both directly through the grazing itself and indirectly through grazing-related human activities. Animal browsing, selective foraging, and trampling affect the natural regeneration process, alter the species composition and structure of the forest ecosystem, and affect soil and nutrient recycling processes. Use of fires to open up, maintain, and improve pastures, and herders harvesting timber for construction or fuelwood, can lead to lowering of treelines and timberlines and narrowing or even disappearance of the timberline ecotone, while grazing on fire sites strongly inhibits regeneration in the treeline area. As a consequence, contrary to expectation, many of the timberlines on south-facing slopes that are grazed are lower than on the corresponding cooler north-facing slopes. However, if not disturbed by human activities, timberlines and treelines on the southern slopes are at the same or higher altitude than *those on the northern slopes. In recent decades, the region has witnessed great changes in the human disturbance regimes due to China's rapid socioeconomic development. Such changes will have profound ecological implications on the ecosystem of the timberline/treeline ecotone. How the current changes will affect local social-ecological resilience merits serious study.*

Keywords: forest ecotone; grazing; pastoralism; Tibetan Plateau; timberline

Introduction

Human society and the ecosystem in which it exists constitute a complex adaptive social ecological system (SES) composed of cultural, political, social, economic, and ecological domains or subsystems linked across temporal and spatial scales. The structure, functions, and dynamics of the SES result from cross-domain interactions at different scales (Holling 1986; Holling 2001; Gunderson and Holling 2002). Changes in sociocultural components such as policies, values, and social institutions can have significant impacts on the ecosystem and the goods and services it provides, which in turn can affect the economic component of the system and people's wellbeing. Similarly, economic components such as the emergence of new economic opportunities, introduction of market systems, or linking to new markets can have a marked impact on the local ecosystem which in turn has an impact on local society (e.g., redistribution of wealth or inequity).

Treelines represent a unique landscape at a high-altitude across the globe. Körner (1998) has provided the most comprehensive description and analysis of the spatial pattern of global treelines up to now, including various hypotheses related to treeline formation and factors such as environmental stress, disturbance, growth limits, and carbon balance (Körner 1998).

The treeline ecotone (Körner 1999; Körner and Paulsen 2004) (also called, as in this volume the timberline ecotone) is the interface between sub-alpine forests and the alpine zone. It is both an area where different ecosystems interact and a venue for many human activities, and represents a special SES with interactions between social subsystems and biological subsystems. The timberline ecotones on the Tibetan Plateau are usually major summer pastures for pastoral communities, habitats for important herbal plants such as caterpillar fungus (*Cordyceps* spp.), and/or sites for tourism. In particular, agropastoral transhumance is an age-old and widespread indigenous livelihood system in the eastern part of the Tibetan Plateau. The SES we see today is the result of millennia of interactions and co-evolution of human activities and local ecosystems. In recent decades, profound socioeconomic changes have taken place in the mountains of the eastern Tibetan Plateau as a result of China's modernization drive. These socioeconomic changes are bound to have ecological consequences, which will in turn further shape the course of socioeconomic development. Understanding this process will have important implications for sustainable development and building the resilience of the mountain communities of the region.

This paper discusses the interactions between the agropastoral activities and the treeline ecotone ecosystems in the Hengduan Ranges region of the eastern Tibetan Plateau, based on a general literature review of grazing and forest ecosystems and the results of field investigations. We hope that this paper will stimulate the interest of scholars and policy-makers to further understanding of this issue and improve policies to enhance the social-ecological resilience of the mountain regions.

Grazing and Forest Landscapes: A Brief Review

Grazing impacts on forests are complex, multi-faceted, and at multiple scales, and have been widely studied (Putman 1996; Jorritsma et al. 1999; Berlin et al. 2000; Piussi and Farrell 2000; Weisberg and Bugmann 2003).

Grazing affects floral composition and creates habitat heterogeneity, which in turn affects the faunal biodiversity of the forest ecosystem (Milchunas and Lauenroth 1993; Dennis et al. 1998; Krzic et al. 2003). Studies suggest that large scale low-intensity grazing was a key factor in maintaining healthy populations of many endangered and rare species and that cessation of grazing activities has led to a drastic decline in biodiversity (Sickel et al. 2003). Many cases have also been reported in which grazing led to loss of, or no significant change in, biodiversity (Brockway and Lewis 2003). The nature and degree of impact depends on the type of animal, grazing intensity, temporal and spatial distribution of grazing pressure, and stability of the ecosystem itself.

From the forest management perspective, it is believed that grazing severely affects or damages forest regeneration and development (Weisberg and Bugmann 2003). Animal browsing can cause damage to many important tree species and change the species composition, structure, and function of forests and the availability of soil nutrients. Again, the nature and extent of grazing impact on forest regeneration and development depends on the types of animal involved, browsing intensity, and forest species composition (Jorritsma et al. 1999).

Grazing can alter the spatial pattern of vegetation (Adler et al. 2001). Before human directed grazing, grazing by wildlife had a far-reaching impact on the evolution and development of the forest ecosystem. The 'large herbivore hypothesis' (Bradshaw et al. 1999; Vera 2000; Mitchell 2005) suggests that natural forests should be a mosaic matrix of grassland, shrubs, and tree groves, with large herbivores playing a key role in tree regeneration. It is thought that the primeval landscape of Europe was heavily influenced by herbivores, with grazing providing alternative habitats for species dependent on an open environment for survival. The Vera hypothesis suggests that the vegetation of the Eurasian continent in the late Triassic Period co-evolved with various large herbivores to form an open forest structure, similar to what we see today in savannahs. Since most of the animals that once existed in large numbers have now disappeared, the corresponding vegetative structure has also disappeared, and today's forests are dark and dense and not favourable for the previously very abundant forest insects and herbaceous plants. Austrheim et al. (1999) proposed that human activities, especially the grazing which started in prehistoric times, are major factors controlling the community diversity, species composition, and dynamics of open landscapes such as grasslands. They consider that to maintain the existence of such communities, it is necessary to maintain the constant presence of human factors in order to prevent the communities from evolving into forests. It is believed that in the eastern Tibetan Plateau, fires and grazing have prevented the progressional vegetative succession and kept the sub-alpine shrub meadows in a state of disclimax (Wu et al. 1998). The grazing impact on forest vegetation succession depends on the type of animal, grazing intensity, and the vegetation involved (Kuiters and Slim 2002).

Grazing also affects the vegetative pattern by changing the chemical and physical properties and hydrological features of forest or grassland soil as well as the quantity of organic matter and nutrient recycling processes in the ecosystem (Piussi and Farrell 2000; Anderies et al. 2002; Smith et al. 2002; Teague and Dowhower 2003).

Grazing impacts on high-altitude landscapes, including alpine treelines, are common worldwide and can be traced back several millennia. Many grasslands or meadows near or immediately below today's treelines are somewhat related to human activities, with fires being one of the major factors (Körner 1999).

Human activities have played an important role in shaping the treeline positions in Europe and North America (Sveinbjornsson 2000). In the Caucasian mountains, nomadic or semi-nomadic pastoralism has been suggested to be the main factor determining the position of the treelines on the eastern and southern slopes, which are lower than those on the north and west slopes, as well as the distinctive vegetation pattern, which is different on different slopes (Dolukhanov 1978). In the Carpathians of Eastern Europe, timberlines were lowered by 300 to 400 m during the 15th and 16th centuries due to grazing. When grazing activities ceased in the 18th century, significant regeneration occurred at the upper limit of the timberlines, and this regeneration was most vigorous where the timberline had been lowered the most (Plesnik 1978).

It is thought that forests once existed on many northern slopes of the Himalayas but were destroyed by humans and their animals. When the forests at the upper boundary of the timberlines were destroyed, they were replaced by the vegetation that had previously only existed above the timberlines, and this became a secondary landscape dominating the treeline zone (Holzner and Kriechbaum 1998).

Internationally, increasing attention has been paid to how the agricultural intensification process (livestock production in particular) is altering natural landscapes that were previously maintained by human activities (Kampf 2002). A lot of research and practical programmes have been carried out on using wildlife or domestic animals for ecosystem management (Valderrabana and Torrano 2000). In many European countries like Germany large herbivorous animals have been widely used to achieve forest management objectives such as controlling herbaceous invasion, reducing fire hazards, improving species regeneration, and increasing biodiversity. Recognizing the importance of large herbivores in ecosystems, WWF launched its Large Herbivore Initiative (LHI) in 1999 to coordinate the efforts of European countries to reintroduce large herbivores into the ecosystem to address biodiversity conservation issues at ecosystem level or large spatial scales (Berselman 2002).

The Treeline Pattern in the Hengduan Ranges of the Eastern Tibetan Plateau

Treeline positions and treeline species in the eastern Tibetan Plateau show great variation both across the region and among slopes with different aspects. In general, the treeline elevation increases gradually from the southern part and peripheral areas to the northwest interior of the region, reaching the highest altitudes in the Litang-Chamdo region. According to field measurements by the authors using the definitions given by Körner (1998), in the Hengduan Ranges, treelines are mostly around 4,200–4,300 masl in northwest Yunnan (Meili, Baima and Jiawu snow mountains); while in Songpan of Sichuan in the easternmost part of the region, they are mostly 3,800–3,900 masl. Latitude wise, treelines are around 3,600–3,700 masl in Gongga Mountain area and rise up to around 4,400 in Yajiang and Litang and 4,100–4,200 masl in Rangtang of Sichuan (Table 16).

Table 16: **Selected timberline and treeline positions in the eastern Tibetan Plateau (masl)**

Area	Lat. (N)	Long.(E)	Aspect	Timberline (masl)	Treeline (masl)	Location
Deqin	28.511	98.703	S	4,280	4,346	Meili (Lujiaoka)
Deqin	28.494	98.730	NE	4,305	4,324	Meili (Gongga)
Deqin	28.420	98.766	NE	4,330	4,380	Meili (Nuseshigong)
Deqin	28.323	99.087	NE	4,280	4,365	Baima (East Pass)
Deqin	28.384	98.991	NE	4,398	4,414	Baima(West Pass)
Deqin	28.513	98.925	SW	4,314	4,314	Renzhi (Gongka)
Deqin	28.660	98.938	W	4,364	4,380	Jiawu (Puchangbengding)
Mangkang	29.269	98.678	NE	4,202	4,350	Hongla
Luding	29.544	101.973	S	3,719	3,740	Gongga Mt. (Hailuogou)
Rangtang	32.380	100.725	S	4,298	4,320	Erlinchang
Kangding	30.068	101.312	SW	4,350	4,380	Gao Er Si (Near Pass)
Yajiang	30.009	100.867	S	4,300	4,300	Jiaziwan
Litang	30.218	100.258	N	4,427	4,450	Haizi Lake
Songpan	33.054	103.691	NE	3,921	3,960	Gonggangling

Under natural conditions, timberlines and treelines occur in pairs, with a clear timberline ecotone between them. However, in places where human activities are frequent, the forests often end abruptly without a treeline or timberline ecotone, and the timberline is immediately followed by alpine pastures. This occurs mainly where pastures are still in use or grazing has only stopped recently (mostly on sunny or semi-sunny slopes) and/or where fires have caused significant lowering of the timberline. Where there is both a treeline and a timberline, they are usually separated by a 50 to 600 m wide ecotone area, and have an altitudinal difference ranging from 15 to 300 masl.

Temperature is usually the dominant natural driver of treeline/timberline formation. As south-facing slopes are usually warmer than north-facing slopes, treelines and timberlines on south-facing slopes should be able to reach higher positions than on their north-facing counterparts. In many parts of the eastern Tibetan Plateau, however, timberlines are higher on the shady (northern and northwestern) slopes than on the sunny (southern and southeastern) slopes; in northwest Yunnan, the difference can be as much as 150 m. This is the opposite of what would be expected in an unmodified area. Where the south-facing slopes have a visible timberline ecotone, the timberlines and treelines are often at the same level or higher than those on the northern slopes. It appears that the disappearance or lowering of the timberline ecotone on the south-facing slopes is mainly the result of natural fires or fires ignited deliberately by local villagers to improve the pasture.

The major tree species in the timberline and treeline in the Hengduan Ranges are *Abies* spp., *Picea* spp., *Larix* spp., *Sabina* spp., and *Quercus* spp., with clear differences across the region and between slope aspects (Table 17). As a general rule, *Quercus* spp. and *Sabina* spp. are only found on sunny slopes or mountain ridges; *Abies* spp. are the main treeline species regardless of slope in the peripheral parts of the Plateau where treeline climates are usually cold and humid; and *Picea* spp. are the main treeline species on both sunny and shady slopes further into the interior of the Plateau in areas such as such as Hongla (Tibet AR) and Litang (Sichuan). *Larix* spp. are often seen on sunny slopes or mountain ridges above the timberline. It is common to see *Abies* spp. and *Picea* spp. extending from the valley bottom or below the timberline and being replaced at the mountain ridges by *Sabina* spp. and *Larix* spp.

Agropastoralism and Treeline Ecotone Interactions on the Eastern Tibetan Plateau

Interaction of agropastoral activities with the treeline ecotone

Agropastoralism in the eastern Tibetan Plateau is a combination of sedentary farming and mountain transhumance (Yi et al. 2008). Every year, local herders and their domestic animals, mostly yaks, migrate between the settlements at the valley bottoms and the summer pastures in the alpine zone, passing through a dry shrub zone and forest belts, to make full use of the resources in different zones along the altitudinal gradient. Usually, the annual migration starts in May, reaches the alpine zone in middle or late June, and returns to the settlements in late

Table 17: **Dominant treeline species in the Hengduan Ranges of eastern Tibetan Plateau**

Region	South-facing slopes/mountain ridges	North-facing slopes/valley bottoms
Baima Xueshan (Yunnan)	*Abies georgei* Orr; *A. georgei Orr var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *L. potaninii* Batalin *var. macroparpa* Law; *S. saltuaria* (Rehd. et Wils) Cheng et W.T.Wang; *S. pingii* (Cheng ex Ferre) Cheng et W.T.Wang; Q. aquifolioides Rehd. et Wils; *Q. pannosa* Hand.-Nazz.	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *P. likiangensis* (Franch) Pritz; *L. potaninii* Batalin *var. macrocarpa* Law
Meili Xueshan (Yunnan)	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *Q. aquifolioides* Rehd. et Wils	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu
Jiawu Xueshan (Yunnan)	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *P. likiangensis* (Franch) Pritz; *A. forrestii* C.C.Rogers; *S. saltuaria* (Rehd. et Wils) Cheng et W.T. Wang; *S. pingii* (Cheng ex Ferre) Cheng et W.T. Wang; *Q. aquifolioides* Rehd. et Wils; *Q. pannosa* Hand.-Nazz.	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *A. forrestii* C.C. Rogers; *P. likiangensis* (Franch) Pritz
Hongla Xueshan (Tibet)	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *P. likiangensis* (Franch) Pritz; *L. potaninii* Batalin *var. macrocarpa* Law; *S. saltuaria* (Rehd. et Wils) Cheng et W.T. Wang; *S. pingii* (Cheng ex Ferre) Cheng et W.T.Wang; *Q. aquifolioides* Rehd. et Wils; *Q. pannosa* Hand.-Nazz	*A. georgei* Orr; *A. georgei* Orr *var. smithii* (Viguie et Gausen) Cheng et L.K. Fu; *P. likiangensis* (Franch) Pritz; *L. potaninii* Batalin *var. macrocarpa* Law
Rangtang (Sichuan)	*L. potaninii* Batalin *var. macrocarpa* Law; *S. saltuaria* (Rehd. et Wils) Cheng et W.T. Wang; *Q. aquifolioides* Rehd. et Wils; *P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen	*L. potaninii* Batalin *var. macrocarpa* Law; *P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen; *A. squamata* Mast.
Songpan (Sichuan)	*S. saltuaria* (Rehd. et Wils) Cheng et W.T. Wang; *P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen; *A. faxoniana* Rehd. et Wils.; *S. przewalskii* Kom.	*P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen; *A. faxoniana* Rehd. et Wils.
Yajiang (Sichuan)	*S. saltuaria* (Rehd. et Wils) Cheng et W.T. Wang; *Quercus* spp.; *P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen	*P. likiangensis var balfouriana* (Rehd. et Wils.) Cheng ex Chen; *A. squamata* Mast.

September, where the animals winter on hay and crop residues. Each year, the animals spend about 60-120 days in the forests and 60-100 days on the high pastures. The pastoral activities interact with the timberline ecotone in a variety of ways:

Animal grazing and trampling

Browsing, selective foraging, and trampling by animals impacts the vegetation pattern and succession process of forest communities. The forest belt is the major venue for grazing in the study area; in northwest Yunnan, animals spend two to three months a year on average in the forests during their annual migration between the summer and winter pastures. Forest forage includes understorey herbs, shrubs, and young twigs and leaves of tree saplings. Grazing can affect regeneration, species composition, and structure of the forests, and alter the conditions and recycling of soil nutrients. When the animals reach the alpine pastures, the forest edges become the area of choice for setting up summer tents or houses since it is easier to get fuelwood and construction materials and is less windy at night. Thus the treeline zone becomes the major venue for the animals.

Use of fires to open, maintain, or improve pastures

Fire is the cheapest tool for opening pastures and is widely used across the world. In northwest Yunnan, this practice lasted up to the early 1980s. During the collective system period from 1949 to the early 1980s, burning of pastures was conducted in a regular and well-organized way. Subsequently, such use of fire was banned by local governments for fear of forest fires. Even after more than 30 years, the vestiges of past fire use in the region are still highly discernible. Interviews with the communities, and field investigations, confirmed that burning for pastures usually happened close to the timberline on the south-facing slopes, since they are warmer and drier and more suitable for human and animal activities.

Burning for pastures caused a lowering of treelines and timberlines in many places in the region. The newly-opened pastures need to be maintained through regular burning (usually once every 10 years) to remove shrubs, maintain the pasturelandscape, and improve fodder quality. Since fire has been excluded for more than 30 years in northwest Yunnan, shrubs now cover 50-80% of the area and are 50-100 cm high in many pastures, which has a serious negative impact on fodder quality. The shrub encroachment has effectively reduced the intensity of grazing activities at the forest edge and protected the tree seedlings at the timberline.

Grazing on burned sites of natural or accidental fires

Natural (e.g., from lightning and landslides) or human-caused (accidental or incendiary) forest fires were common in the sub-alpine belts across the region. Herders usually find that fire sites provide good pasture. Grazing immediately following fires can strongly inhibit regeneration processes.

Herders harvesting construction timber or fuelwood at the timberline zone.

Herders need timber and wood for building summer houses, heating, cooking, preparing animal feed, and processing dairy products. A traditional summer house requires 4-5 m^3 of timber to construct and has to be replaced every five to six years, and each house consumes around 10 m^3 of fuelwood every year. All this timber and fuelwood is obtained from the timberline-treeline area.

Grazing impacts on treeline forest regeneration

To investigate the impacts of grazing on treeline forest regeneration, we studied 12 timberline ecotone sites across northwest Yunnan. The sites were grouped into plots with normal grazing and plots with low or no grazing. A detailed survey was made of seedling and young tree occurrence in a 20 x 50 m^2 plot within each site. The results are shown in Table 18. The impact of grazing activities on regeneration is clear. The ecotone sites with low or no grazing had an average of 604 seedlings/ha (Class I), compared to only 56 seedlings/ha in grazed plots. There was a similar difference for saplings (Class II). The proportion of class I and II seedlings is also higher in relative terms in plots without grazing activities than in plots with grazing activities; seedlings and saplings together accounted for 67% of trees in ungrazed plots but only 30% in plots with normal grazing. Ungrazed plots had 2,358 trees on average and grazed plots only 642. This shows that grazing caused a significant reduction in tree seedlings and strongly affected the natural regeneration process in the ecotone. Using spatial point analysis, Zhang et al. (2008) suggested that grazing reduced the space occupation capacity of the timberline tree communities and tree populations disturbed by grazing activities exhibit a degrading or stable population structure with fewer seedlings and a lower seedling survival rate.

The survey also indicated that shrubs in the treeline ecotone could provide protection for tree seedlings and enhance seedling establishment. Natural treeline ecotones usually have a well-developed shrub layer (*Rhododendron* spp., *Spiraea* spp., *Lonicera* spp.) in terms of both height and cover, which decreases with elevation and distance from the timberline. However, the shrub layer above a non-natural timberline, which is more abrupt, is usually lower in height and less dense due to removal by fire and grazing as well as changed microclimate

Table 18: **Density of trees in different size classes in the survey plots**

Treatment	Sample plot	Size Class					Total
		I	II	III	IV	V	
Normal grazing	1	58	57	148	92	63	418
	2	224	321	279	245	27	1097
	3	0	14	400	114	21	550
	4	0	93	80	180	120	473
	5	0	187	253	133	100	673
	Mean	**56.4**	**134.4**	**232.0**	**152.8**	**66.2**	**642.2**
Low or no grazing	6	17	100	217	100	125	558
	7	11	31	267	56	39	403
	8	12	250	227	31	35	554
	9	2,917	5,208	1,525	467	217	10,333
	10	544	633	856	222	28	2283
	11	725	550	325	300	283	2183
	12	0	40	80	30	40	190
	Mean	**603.7**	**973.1**	**499.6**	**172.3**	**109.6**	**2,357.7**

I = first-year seedlings (<10 cm high); II = saplings (10<50 cm high); III = young trees (>50 cm high and <7.5 cm DBH); IV = poles (DBH 7.5<17.5 cm); and V = adult trees (DBH >17.5 cm (Camarero et al. 2000).

conditions (strong radiation, extreme temperature, and desiccation). Lacking shrub protection, tree seedlings are easily affected by browsing and trampling of domestic animals, and the adverse climatic conditions are also unfavourable for the establishment of treeline species (especially *Abies* spp.).

Grazing and treeline landscape across the eastern Tibetan Plateau

It is clear that grazing and related human activities have caused a lowering of the timberline-treeline zone and narrowing or disappearance of the timberline ecotone in many localities. As mentioned above, the timberlines and treelines in the eastern Tibetan Plateau are usually higher on the cooler northern or northeastern slopes than on the sunny southern or southwestern slopes. The difference ranges from 20-30 m to 100-300 m. Theoretically, the treelines should be higher on the southern slopes in the northern hemisphere. However, the southern slopes are often preferred for grazing, and people remove vegetation at the timberline to improve the pastures (Wu et al. 1998). For example, in Gongga in the Meili Mountains in northwest Yunnan, the timberlines and treelines on the northeastern slope, where there is no grazing, extend up to 4,305 masl and 4,324 masl, respectively; but on the southwestern slopes with grazing, the timberline is at 4,207 masl and there is no visible timberline ecotone. As frequently seen in the region, timberlines and treelines on southern slopes not disturbed by human activities reach the same or greater heights than those on the northern slopes.

Grazing and burning are interrelated factors that affect the alpine vegetation pattern and often work together. As Kramer et al. (2003) pointed out, fire can push ecosystem consumers and producers to a new equilibrium and grazing can help to maintain the new state. For example, on the eastern Tibetan Plateau, fires can convert *Abies* spp. and *Rhododendron* spp. forest into *Rhododendron* spp. shrubland, which can be further turned into alpine meadows by grazing. Seedlings of *Abies* spp. are very rare under rhododendron shrubs, and it is very difficult for rhododendron shrublands to evolve into forest of *Abies* spp. On sunny slopes around 3,900 masl, *Abies* spp. forests were usually replaced by forest of *Larix* spp. After major disturbances such as fires; if well protected, such *Larix* spp. forest can again evolve into *Abies* spp. forest, but the process can be delayed by grazing and other human disturbances.

Changing Agropastoralism and the Ecological Implications for the Timberline Zone

Agropastoral transhumance with a combination of lowland farming and vertical migratory pastoralism is a traditional economic form widely practised in the studied region which complies with the vertical distribution of climatic and biological resources. Human activities in the eastern Tibetan Plateau, especially combined farming and pastoral activities, can be traced back more than 5,000 years (Aldenderfer et al. 2004) and have played an important role in shaping the vegetation landscape of the region.

Over the past three decades, drastic changes have taken place in agropastoralism in the region, as reflected in the type and number of livestock kept, economic importance, pastoral-agro relations, and seasonal migration patterns (Yi et al. 2007; Yi et al. 2008). The trend is ongoing and is seen in all the mountain areas across the Hindu Kush Himalayas. An observable result is the major shift of overall grazing pressure to lower elevation areas, with a decline in both stocking rate and length of annual utilization of the alpine pastures.

Such changes have profound ecological implications. The timberline-treeline pattern (boundaries, structure, and species composition) driven by human factors will change with changes in the anthropogenic disturbance regime. Reduced grazing intensity and cessation of fire use will result in an increase in the cover and height of shrubs at and above those timberlines which have been lowered by fires and maintained by grazing activities. This increase in shrub layer will create microhabitats for the successful establishment of tree seedlings at the timberline, and reduce animal browsing and trampling on the seedlings by making it more difficult for animals to pass, creating conditions for the upward expansion of the timberline forest communities.

The ecological changes will result in changes in the goods and services the ecosystem can provide, which will further impact the local socioeconomic system. The eastern Tibetan Plateau is one of the world's major biodiversity hotspot areas. The timberline-treeline zone provides habitat for many endemic floral and faunal species, including some economically important species (e.g., *Cordyceps sinensis*), and changes in the habitat may threaten their very existence. Grazing was frequently cited as a major cause of biodiversity loss in the region by policymakers and nature reserve managers. However, indiscriminative exclusion of grazing from ecosystems often results in unexpected consequences on biodiversity.

Further Research

From the point of view of both scientific understanding and development, the following questions merit special attention for further studies:

1. **Long-term monitoring of treeline changes is needed at a larger temporal and spatial scale, taking into account both socioeconomic and climate changes.** As drastic socioeconomic changes are taking place across the region, it is of both academic and practical interest to know how local ecosystems, particularly the timberline ecotone, is responding to such changes. Monitoring should include the changes in treeline position, biodiversity, and ecosystem services in the timberline ecotones across the region. As the region is also sensitive to climate change, the monitoring must be able to distinguish the different contributions of socioeconomic and climatic factors to the changes in local ecosystems.
2. **Reconstructing historical grazing-vegetation interactions in the Tibetan Plateau.** Palaeoecological approaches should be used to reconstruct former grazing-vegetation interactions on the Tibetan Plateau in order to understand the roles of human activities and

climatic factors in shaping the current vegetative landscape of the Tibetan Plateau, especially at the treeline level.

3. **How will the current trends affect local social-ecological resilience?**
   For example, how will the loss of indigenous knowledge and culture, and changes in the local ecosystem, as a result of externally-driven socioeconomic change affect the resilience of local communities?

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