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Shrubland or Pasture? Restoration of Degraded Meadows in the Mountains of Bhutan

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Invasion of high-altitude grasslands by unpalatable shrubs poses a serious threat to the livelihoods of mountain herders. To address the issue, a study was conducted on shrub-infested grasslands in the Himalayan rangeland of Bhutan to compare the effects of prescribed burning and vegetation cutting on the relative abundance of several key types of plants, forage dry matter production, and yak carrying capacity, and to suggest appropriate time intervals for the application of management measures. The proportions of broadleaf and grass and palatable dry matter yield were higher on sites with a northwesterly aspect. Prescribed burning led to a significant increase in the proportion of all plant categories except rhododendron. Compared with the control (no treatment) and cutting, prescribed burning resulted in significantly higher palatable dry matter yield, which increased during the first 4 years after burning and then declined in the following 2 years. The annual carrying capacity per hectare for the burned plots was 0.23 livestock units, compared to 0.05 livestock units for the control and cut plots. These results suggest that prescribed burning is an effective tool to restore high-altitude shrub-dominated grasslands. We suggest a time interval of 6 years between burnings.

Keywords: *Broadleaf; dry matter; prescribed burning; relative abundance; rhododendron; sedge; vegetation cutting; rangeland restoration; Bhutan.*

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Introduction

High-altitude meadows constitute about 54% of the total rangeland in the Himalayan ranges (Pariyar 1995) and form a major source of forage for domestic cattle and wildlife. The rangeland communities rely heavily on these meadows to sustain livestock production and the fragile economy in one of the world's most challenging environments. However, over the last few decades, invasion of meadows by unpalatable shrubs, mainly *Rhododendron anthopogon* and *Rhododendron setosum* and some *Juniper* sp, has significantly reduced forage production (Chophyel 2009), posing a serious threat to the herders' livelihood.

Globally, most scientific discussions of rangeland issues have focused on desertification due to human disturbance and overexploitation (Zhou et al 2005; Dong et al 2010; Harris 2010; Li et al 2011). Large numbers of studies on grassland management originate from the rangelands of Australia and the United States. Studies have amply dealt with rangeland issues in arid environments (Guevara et al 1999; Ansley et al 2006; Gucker and Bunting 2011), but studies specific to rehabilitation of high-altitude grasslands in the Himalayan region are limited. Because of its rugged terrain and large variations in altitude (Timilsina et al 2007; Gairola et al 2008), the Himalayan region has diverse ecosystems where the need to test grassland rehabilitation techniques is crucial.

Bush encroachment alters habitat structure, decreases herbaceous production, and is a major threat to livestock production and natural resource conservation (O'Connor and Crow 1999). Increase in the proportion of woody species is generally reported to be the combined effect of global warming, fire suppression, and overgrazing (Miller and Rose 1999), leading to conversion of open grasslands to woody shrublands (Teague and Dowhower 2004). When a threshold of woody encroachment is attained, woody species can resist changes in management (Parmenter 2008), including removal of grazing pressure (Klinger et al 1994). This negatively affects wildlife habitat, biological diversity, and watershed and ecosystem function (West and Young 2000); decreases herbaceous production and diversity; and increases bare ground and soil erosion potential (Scholes and Archer 1997). External disturbances, leading to disruption of the balance between woody and herbaceous plants, result in such phenomena (Papanastasis 1992).

Of the management options available for addressing such situations, fire is a common tool used for vegetation management and rangeland ecosystem sustainability (DiTomaso et al 2010). The effects of fire have been studied extensively (Guevara et al 1999). Burning is used for shrub control (Friedel et al 1990) and is relatively inexpensive (Harrell and Zedaker 2010). Prescribed burning restores native species to grassland communities (Dyer et al 1996; Meyer and Schiffman 1999), increases the nutritional quality of understory vegetation (Cook et al 1994), increases available soil nutrients (Debano and Klopatek 1988; Blank et al 1996), and reduces competition from woody species (Tietje et al 2001). However, as fire environments and vegetation are highly variable, it is difficult to generalize about the response of herbaceous vegetation to fire (Guevara et al 1999). Furthermore, the highly specific nature of rangeland ecosystems does not ensure successful application of techniques used at one site to another site (Hocking and Mattick 1993). In the Himalaya, mixed farming is largely based on integrated use of natural resources; thus, management to restore shrub-dominated meadows must be cost effective, providing opportunities for both biological conservation and resource utilization.

This paper presents the results of 2 experimentally tested alternatives for managing vegetation on the high-altitude grasslands of Bhutan, where the rangeland ecosystems at elevations above 4000 m are increasingly influenced by the rhododendron species. Ocular assessment shows decline in overall size of meadows due to encroachment by these shrubs. An estimated 22% of grazing area has been lost to shrub encroachment over the last decade (Chophyel 2009). Although prescribed burning has been suggested as a technique to restore degraded high-altitude grasslands (Chophyel 2009), lack of explicit studies limits its use as a vegetation management tool. More research is needed on the effects of fire on different plant categories in the Himalayan rangeland. Accordingly, the objectives of this study were (1) to compare the effects of prescribed burning and vegetation cutting on the relative abundance of different plants, dry matter (DM) yield, and the yak carrying capacity of high-altitude grasslands, and (2) to estimate the ideal time interval for application of management measures, based on trends in forage production over time.

Material and methods

Study sites and design

The study was conducted from 2006 to 2011. The study area, Soe Yaksa in Paro *dzongkhag* (district), is the main grazing ground for migratory yak herds and is representative of the high-altitude grasslands of Bhutan. Based on the severity of dominance by shrubs, 3 experimental sites at elevations above the tree line were selected. Characteristics of the study sites are presented in Table 1. Herbaceous species included mainly grass, sedge, broadleaf, and traces of ferns and moss.

The study used a randomized complete block design. The management approaches were (1) prescribed burning, (2) vegetation cutting, and (3) no burning or cutting (the control). Each treatment was repeated 3 times per site, with 3 plots per treatment per site. Treatments were applied only once, in February 2006. For biomass assessment, an iron cage was placed in each plot (3 cages per treatment per site). Plot size was 100 m^2, for a total of 900 m^2 per location. The dimensions of a cage were 0.8 m × 0.48 m at the base, 0.7 m × 0.4 m at the top, and 0.3 m in height. Following measurements in each year, the cages were rotated within each plot. Field measurements for both species composition and DM yields were carried out on the dates listed in Table 1. Since the cages were too small to include woody shrubs, rhododendron was excluded from them. Therefore, only the relative abundance of rhododendron was measured and not the DM.

The burn severity was determined by assessing the changes in plant materials aboveground, while the survival rate of roots was measured to evaluate the change belowground (Ryan and Noste 1985; Keeley 2009).

TABLE 1 Characteristics of study sites and harvest dates at each site. (Table extended on next page.)

Study site	Altitude (m)	Aspect	Latitude and longitude
Sutena	4300	West	27°42′03″N
			89°21′43.1″E
Shebjidingkha	4160	Northwest	27°41′31.1″N
			89°21′09.4″E
Balung	4200	Southwest	27°41′29.1″N
			89°20′21.7″E

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Measurement of relative abundance of botanical groups and live roots

Relative abundance of 4 major botanical groups—broadleaf, sedge, grass, and rhododendron—was measured each year at the end of the growing season, using the modified point intercept method (Walker 1970). All 4 groups are common on high-altitude rangelands, but only the first 3 have value as forage for livestock. We defined relative abundance as the number of plants of a given botanical group relative to all groups recorded. Four transect lines were randomly laid out per plot, each 1 m long and marked with 20 points spaced 5 cm apart, for a total of 80 points per plot. The plant species intercepted by the 20 points were recorded (leading to a total of 80 points read from a single plot). Relative abundance of each botanical group was expressed as a percentage of the total plants recorded. Bare ground was also recorded to estimate the plant cover.

A metal frame (0.25 m^2) was randomly laid out 4 times per plot, and the number of live and dead roots within it was recorded. Measurements were carried out at the end of the growing season in the first year of the study only. Final estimates were expressed as percentage survival of roots. Because our interest was in assessing the severity of burning, these measurements were carried out only for the prescribed burning treatment.

Measurement of forage dry matter yield and estimation of carrying capacity

The annual DM production was also estimated towards the end of the growing season by measuring the biomass inside the iron cages, using the hand clipping method ('t Mannetje 2000). The palatability of different species was determined with the help of an experienced herder who helped us identify the plant species grazed or refused by yak, the main livestock species in the study area and used as the reference animal in our study. The harvested plant materials were separated into palatable and unpalatable parts and weighed. The palatable plants were sedge, broadleaf, and grass. Representative subsamples weighing about 300 g were collected and oven dried at 60°C for 48 hours. Dry matter percentages were estimated.

We defined yak carrying capacity as the total number of yak that a hectare of meadow can support on a sustainable basis. The computation defined 1 standard Bhutanese livestock unit as an adult bovine weighing about 300 kg with a daily DM requirement of 2% of live body weight (Samdup et al 2010). Carrying capacity, based on average palatable DM yield per year, was expressed as livestock unit per year per hectare.

Data analysis

The data set was checked for normal distribution and homogeneity of variance. The effects of the site, the treatment, and interactions between the two on species composition and DM yield (consumable and nonconsumable) were examined using univariate ANOVA (analysis of variance). The data were averaged across years, and overall differences of means between management treatments were tested with 1-way ANOVA. Differences in means were tested with Tukey's least-significant-difference test. Differences were considered significant when P values were less than 0.05. We analyzed the data set using SPSS 19 (Landau and Everitt 2004).

Results and discussion

Effects of site and management measures on species composition

Common species of broadleaf, sedge, grass, and rhododendron are presented in Table 2. The proportions of broadleaf and grass differed significantly between sites (Table 3), which probably resulted from variations in microclimate that influence many grassland species (Bennie et al 2006). Greater proportions of broadleaf and grass were found on sites with a northwesterly aspect, suggesting that aspect probably explains the differences in the proportions of botanical groups between sites. In the Himalaya, sites with a northerly aspect receive less sunlight and more moisture, while sites with a southerly

TABLE 1 Extended. (First part of Table 1 on previous page.)

Date of harvest					
2006	2007	2008	2009	2010	2011
16 Oct	10 Oct	22 Oct	23 Sep	07 Sep	09 Oct
10 Oct	13 Oct	20 Oct	21 Sep	09 Sep	11 Oct
14 Oct	14 Oct	21 Oct	17 Sep	11 Sep	13 Nov

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TABLE 2 Common species of grass, broadleaf, sedge, and rhododendron in high-altitude rangeland in Bhutan.

Grass	Broadleaf	Sedge	Rhododendron
Agrostis inaequiglumis	*Aster himalaicus*	*Carex duthiei*	*Rhododendron anthopogon*
Agrostis myriantha	*Anaphalis nepalensis*	*Carex haematostoma*	*Rhododendron setosum*
Agrostis nagensis	*Dubyaea hispida*	*Carex longipes*	*Juniperus* sp[a]
Agrostis nervosa	*Gentiana prolata*	*Fimbristylis complanata*	
Agrostis pilosula	*Pedicularis siphonantha*	*Kobresia uncinoides*	
Agrostis triaristata	*Saxifraga parnassifolia*	*Kobresia prainii*	
Agrostis zenkeri	*Saxifraga wardii*		
Arundinella hookeri	*Saussurea yakla*		
Brachypodium sylvaticum	*Saussurea uniflora*		
Bromus himalaicus	*Taraxacum* sp		
Elymus nutans			
Elymus sikkimensis			
Festuca bhutanica			

[a]Junipers are included in this group because their presence was minimal.

aspect are warmer and drier (Polunin and Stainton 1984). Soil moisture plays a more important role than sunlight in the vegetation dynamics of the Himalayan rangeland (Paudel and Andersen 2012). Thus, the higher percentage cover of botanical groups on sites with a northwesterly aspect could be attributed to higher soil moisture levels. Differences in soil moisture levels between the site aspects might have resulted from differences in insolation period (Sharma et al 2010).

The effect of site and treatment interaction was not significant for any of the botanical groups (Table 3). Site had a significant effect only on broadleaf and grass. The proportion of broadleaf was significantly higher at Shebjidingkha and Balung than at Sutena. The proportion of grass was significantly higher only at Shebjidingkha.

The postfire assessment of aboveground vegetation showed charred plants with dead twigs (Figure 1) and a root survival rate for rhododendron of over 60% (Table 3). Assessment of burned materials indicated that the prescribed burning was of medium severity (Ryan and Noste 1985; Keeley 2009). While dominance by rhododendrons resulted in lesser proportions of broadleaf, sedge, and grass, fire significantly altered

TABLE 3 Relative abundance of botanical groups across experimental sites and management treatments.[a] (Table extended on next page.)

	Relative abundance (%)		
	Broadleaf	Sedge	Grass
Site			
Sutena	14.2^{B}	13.0	03.9^{B}
Shebjidingkha	26.1^{A}	09.0	06.8^{A}
Balung	22.6^{A}	10.1	02.5^{B}
Treatment			
Control (no treatment)	10.7^{B}	04.5^{B}	01.6^{B}
Prescribed burning	34.4^{A}	23.5^{A}	08.7^{A}
Vegetation cutting	12.8^{B}	05.8^{B}	02.6^{B}
Significance			
Site	***	ns	***
Treatment	***	***	***
Site × treatment	ns	ns	ns

[a]Means were computed from 6 years of data. Relative abundance was determined by the point intercept method. Means for site and treatment interactions are not shown due to nonsignificant effects on relative abundance. Means with different letters (A, B) are significantly different. ns, not significant; α, not measured.

**$P < 0.01$.

***$P < 0.001$.

domination of the vegetation structure from shrubs to herbaceous species.

Consistent increases in proportions of broadleaf and sedge in the burned plots also contributed to high palatable DM yield. This was probably the result of reduced competition following removal of woody species (Tietje et al 2001) and creation of open space for recruitment of herbaceous species. The postfire increase in proportions of broadleaf and sedge could also partly be explained by their dominance at elevations above 4000 m (Roder et al 2001). Although we lacked data on soil nutrients, a few explanations are possible from the soil fertility standpoint. The postfire increase in proportions of broadleaf and sedge might also be the result of enhanced availability of soil nutrients (Roder et al 1992; Blank et al 1996), with increased mineralization rates favoring emergence of species (Gurlevik et al 2004). Particularly on grasslands, the soil fertility under shrubs is reported to be significantly high (White et al 2006).

Our results corroborate the frequently stated hypothesis that prescribed burning can alter vegetation patterns from shrub dominated to grassland (Meyer and Schiffman 1999; Rostagno et al 2006). The proportions of rhododendrons were significantly higher with cutting and with no treatment. Especially for cutting, this can be attributed to heavy sprouting of rhododendrons after mechanical cutting, similar to findings reported for *Rhododendron maximum* (Harrell and Zedaker 2010). Mechanical clearing of woody plants is also reported to stimulate recruitment of woody plant seedlings (Ansley et al 2006). This illustrates the futility of trying to control rhododendron shrubs by cutting.

Effects of site and management measures on forage dry matter production

The effect of site and treatment interaction was not significant for either palatable or unpalatable DM yield (Table 4). The palatable DM yield difference between treatments was nonsignificant in the first year (Figure 2). However, prescribed burning showed significantly higher DM yield beginning in the second year. The yield difference between the control (no treatment) and cutting was nonsignificant throughout the study period. The average palatable DM yield of 1.03 t ha^{-1} in the burned plot was higher than the annual DM production of 0.29 t ha^{-1} estimated for high-altitude grasslands (Roder et al 2001). Prescribed burning resulted in up to 15 times higher palatable DM yield than vegetation cutting or the control, demonstrating that fire could be a reliable tool for restoring shrub-dominated meadows.

The carrying capacity of burned plots was about 0.23 livestock units per hectare (or 1 livestock unit per 4.5 hectares), whereas control plots and those undergoing vegetation cutting had carrying capacity below 0.05 livestock units per hectare (Table 4). These results reveal that reduction of rhododendron shrubs through

TABLE 3 Extended. (First part of Table 3 on previous page.)

	Relative abundance (%)			
	Rhododendron	Moss	Cover	Live roots
Site				
Sutena	59.7	04.4	96.1	53.0
Shebjidingkha	52.0	02.6	96.9	68.3
Balung	57.9	02.5	97.0	61.7
Treatment				
Control (no treatment)	80.5^{A}	01.8^{B}	99.5^{A}	α
Prescribed burning	16.3^{B}	06.5^{A}	91.2^{B}	61.7
Vegetation cutting	75.2^{A}	02.1^{B}	98.9^{A}	α
Significance				
Site	ns	ns	ns	ns
Treatment	***	**	***	_
Site × treatment	ns	ns	ns	ns

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FIGURE 1 Rhododendron shrubs above 4100 m altitude at Soe Yaksa after prescribed burning. (Photo by Thrimshing Yonten)

prescribed burning can lead to 4.5 times as much carrying capacity as cutting or no treatment. The estimated carrying capacity after prescribed burning was also higher than the 0.10 livestock unit per hectare previously estimated for high-altitude regions (Dorjee 1986).

Implications for management

Assessment of the production of palatable DM over several years was useful in estimating the time interval that rhododendrons might require to return to their prefire levels. Prescribed burning showed a significant increase in palatable DM yield, which peaked in 2009, followed by a decline in 2010 and 2011 (Figure 2). The gradual yield increase until 2009 suggests that rhododendrons were probably suppressed but became resilient in 2010. Studies on Himalayan rangelands report an average forage DM yield below 1 ton per hectare (Pariyar 1995; Singh 1995). In our study, the palatable DM yield was slightly higher, which is most probably the effect of prescribed burning. This suggests that, if herders wish to maintain an average palatable DM yield of about 1 ton per hectare, they should carry out prescribed burnings about every 6 years. Our results confirm the need to have frequent fires to break the resilience of shrubs and to cause a shift from shrubland to grassland (Rostagno et al 2006; Cabrera et al 2008). These results also suggest that it is not necessary to burn the vegetation annually, as traditionally practiced by rangeland herders (Ura 2002). Lack of change in palatable DM after cutting clearly demonstrates that cutting is not the right management option to control rhododendron. Further, cutting to control shrubs is expensive (Harrell and Zedaker 2010).

Conclusions

Although no large-scale empirical studies exist for Bhutan, encroachment of high-altitude meadows by shrubs is widely thought to be the consequence of a ban on the use of fire for grassland improvement (Gyamtsho 1996; MoA 2001) and a strict policy on environmental

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TABLE 4 Palatable dry matter yields across experimental sites and management treatments.[a)]

Site/treatment	Palatable DM (t ha^{-1})	Carrying capacity (LUY ha^{-1})
Site		
Sutena	0.33	0.14
Shebjidingkha	0.45	0.14
Balung	0.43	0.17
Treatment		
Control (no treatment)	0.05^{B}	0.04^{B}
Prescribed burning	1.03^{A}	0.23^{A}
Vegetation cutting	0.08^{B}	0.03^{B}
Significance		
Site	ns	ns
Treatment	***	***
Site × treatment	ns	ns

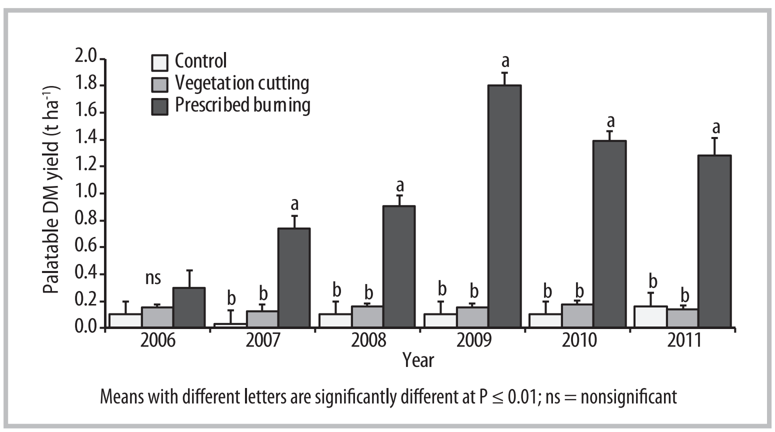
[a)]Means were computed from DM yield data collected over 6 years. Means for site and treatment interactions are not shown due to nonsignificant effects on dry matter yield and carrying capacity. Means with different letters (A, B) are significantly different. DM, dry matter; LUY, livestock unit per year; ns, not significant.
***$P < 0.001$.

conservation, prohibiting the use of fire to manage forested vegetation (Chophyel 2009). The shrinking size of grasslands and gradual rural-to-urban migration are probably an indication that conservation goals either overlook or do not adequately address livelihood issues. Therefore, there is a need to reassess the appropriateness of conservation policies and reflect on livelihood issues.

Our study highlights that prescribed burning at specific intervals is an effective tool to restore shrub-infested high-altitude grasslands. The study results may have wider application in other parts of the Himalayan region sharing similar issues and environmental conditions. Given the cold and humid conditions above 4000 m, and based on a single burning of moderate severity, a time interval of 6 years between prescribed burns is suggested. Prescribed burning results in a large increase in palatable DM, which leads to higher animal carrying capacity. It should be carried out cautiously and with an eye to weather conditions, however, because fire temporarily exposes the ground and leaves it vulnerable to erosion and sedimentation.

In view of certain limitations in our study, we recommend further research in similar environments to evaluate the effects of different fire intensities on vegetation structure, DM production, forage quality, and soil fertility. There is also a need for further investigation of the cumulative effect of management treatments on woody species.

FIGURE 2 Production of palatable dry matter following prescribed burning and vegetation cutting.



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