

Himalayan medicinal plant diversity in an ecologically complex high altitude anthropogenic landscape, Dolpo, Nepal

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SUMMARY

The conservation of high-altitude medicinal plants is of concern throughout the Himalayan region, because they are important for traditional health care and in large-scale collection for trade. Because little is known regarding their conservation status in relation to the diversity of land-use patterns and habitats, this paper explores patterns of species composition and diversity of medicinal plants in five different pasture types in a traditionally-managed high-altitude landscape in northwest Nepal. Environmental variables, including human activities, strongly affected species composition, diversity and cover-abundance of medicinal plant species. Species richness of rare and commercially threatened medicinal plants (CTMP) showed patterns similar to overall medicinal plant species richness. Sub-alpine meadows, which have intermediate levels of human pressure related to grazing and relatively high levels of resource availability in terms of rainfall and soil nutrients, were richer in medicinal-plant species than alpine meadows. The coexistence of various plant communities under different human management regimes also enhanced landscape-level species diversity by maintaining some species restricted to particular habitat or pasture types. A number of medicinal plant species reported to be resistant to grazing were most abundant in heavily grazed sites. This pattern suggests that medicinal plant species may be positively influenced, to a certain extent, by human activities (mainly grazing). The combination of grazing and high levels of harvesting, however, had a negative impact on diversity and cover-abundance of rare and CTMP species. Maintenance of medicinal plant diversity and cover-abundance is critically dependent on managing grazing and resource harvesting to maintain levels that are both ecologically and economically sustainable. Forage for livestock and medicinal plants for local health care cannot be managed independently; a systems approach is needed, incorporating social management to accommodate the needs of different users. This could be achieved by maintenance of a mosaic landscape, in which

different use patterns and pressures, reflecting the values attached to resources by different users and favouring different types of biodiversity, co-exist.

Keywords: conservation, grazing, Himalaya, human impact, landscape heterogeneity, medicinal plants, rare species, species diversity

INTRODUCTION

A large proportion of high-altitude landscapes in the Himalaya have been transformed over a long period of time by humans' presence and their diverse activities, including agropastoralism and extraction of natural products (Aumeeruddy-Thomas *et al.* 2004; Bauer 2004). In addition to their natural resource value, Himalayan landscapes have long been socially appropriated and have strong cultural meanings (Smadja 2003). Medicinal and aromatic plants (MP) are among the key natural resources of the Himalaya, and have long been extracted both for local use and trade (Aumeeruddy-Thomas 2002; Olsen & Larsen 2003). While MP have thrived in highland landscapes in a context of low human and livestock densities, two recent phenomena pose conservation and management issues. One is the great increase in livestock density; the other is a great increase in demand for MP in international trade (Tandon *et al.* 2001). Although fragmentary information exists on the distribution and status of certain species (see Airi *et al.* 2000), no systematic study has been conducted of the patterns of MP species diversity and abundance in relation to environmental factors, including human activities. Human factors are complex, and depend upon social dynamics, knowledge systems and adaptive approaches to different ecological constraints.

In the Himalaya, 'traditionally-managed landscapes' or 'traditional management of natural resources' are generally based on subsistence low-scale agricultural systems. We portray these systems as traditional because they are based on norms and values of local societies which differ from more global modern industrialized societies. Himalayan landscapes have been shaped by the highly unstable characteristics of this mountain range, as well as by the agropastoral activities of a diversity of societies, which have carved out terraces, grazed livestock and used natural resources over centuries. In this context, and given the secular interactions between societies and nature in the region, the environment cannot be seen as an undisturbed stable ecosystem, but as the product of man's activities combined with 'natural' patterns that long pre-date

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human presence (Dobremez 1976; Smadja 2003; Ives 2004; Byers 2005).

In traditionally-managed landscapes, varying intensities and mechanisms of resource use create and maintain small-scale patchiness and diversity (Sullivan 1999). Studies from the mountain regions of Europe have shown that traditionally-managed sub-alpine grasslands show high levels of plant species diversity, including several rare and vulnerable species (for example Austrheim *et al.* 1999; Vandvik & Birks 2004). Cessation of management increases the standing crop of plant biomass and reduces species diversity. Continuous low-intensity human activity is thus needed to maintain species diversity in such landscapes (Dullinger *et al.* 2003). In many developed countries traditionally-managed pastures are therefore considered to have high conservation value, and efforts have been made to maintain them (for example Pärt & Söderström 1999).

As is frequent in mountain regions, pasture lands resulting from the interactions between livestock grazing and the natural environment are an important component of land-use pattern. The effects of grazing on species diversity depend on environmental factors, including productivity of the site, land-use history and the total local plant species pool (Zobel 1997; Austrheim & Eriksson 2001). Low to moderate levels of grazing increase species richness, due to reduced plant competition and enhanced regeneration, but species diversity could decrease with higher levels of grazing, due to elimination of all but species that are resistant (not grazed) or tolerant (grazed, but with little negative effect) to grazing (see Olff & Ritchie 1998). In the Himalaya, many species that are not eaten by livestock, such as *Aconitum spicatum*, *Artemisia* spp., *Elsholtzia eriostachya*, *Geranium pratense* and *Rumex nepalensis*, are high value MP frequently used by traditional healers (Lama *et al.* 2001). Some of these species have been reported to increase in abundance in certain grazed areas in the Himalaya (Miehe 1997). Plants can cope with herbivores by mechanical means or by producing toxic secondary compounds (Cronin *et al.* 1978; Rosenthal & Kotanen 1994), some of which are frequent constituents of plants used in traditional medicine. We thus observe different values attributed to resource species by different users: healers on one hand, who value some grazing-resistant species as medicinal plants, and pastoralists on the other hand, for whom a few types of herbs and grasses of high quality are more valued than the unpalatable MP species. A shift in vegetation composition from palatable to unpalatable species would reduce the capacity of the rangeland ecosystem to support grazing animals. A decrease in the capacity of rangelands may have serious socioeconomic implications for pastoralists living in the Himalaya (Miller 2000). Heavy grazing is known to cause simplification of ecosystem structure, life forms and species diversity, a situation which may eventually lead to impaired ecosystem functioning (Austrheim & Eriksson 2001). This paper aims at analysing MP species diversity in this context of differential use pattern of a Himalayan high-altitude landscape.

We report results of an ecological survey to assess the patterns of species composition and richness in a high-altitude traditional agro-ecosystem in the Nepal Himalaya, with particular focus on MP species. We assessed species composition and richness in relation to human resource-use patterns. To better interpret the causes of change in these variables, other environmental factors that may influence species composition and diversity were also investigated.

METHODS

Study area

The study was conducted in Shey-Phoksundo National Park and its buffer zone in north-western Nepal, an area characterized by a trans-Himalayan climate with low rainfall (450–800 mm yr⁻¹). Snowfall starts in October and the area remains under snow for up to six months until March. Tree line altitude varies from 3700 to 4000 m, with *Abies spectabilis*–*Betula utilis* forest below the tree line and, above it, alpine thickets of *Lonicera*, *Rhododendron* and *Salix* forming closed vegetational cover on shady N–NW-facing slopes, and shrubs such as *Cotoneaster* and *Juniperus* on dry S–SE-facing slopes. Alpine meadows cover extensive areas, descending to 3500 m altitude.

About 500 inhabitants (in 93 households) live in the settlements that we studied inside the Park, and 3950 people (in 745 households) in the buffer zone. Humans have inhabited the study area and used its pasture resources for at least 1000 years (Aumeeruddy-Thomas *et al.* 2004). The major plant resources extracted from high-altitude areas include medicinal plants, food, firewood and fodder grass. Agriculture is restricted to areas below 3900 m. MP are highly important for both local healthcare and livelihood through benefits gained from trade. MP are harvested for trade mainly in the buffer zone.

The local system of pasture management involves seasonal grazing of livestock in high and lower altitude pastures during summer and winter, respectively. In summer pastures, livestock grazing is rotational between different sub-pastures. The average livestock holding is 12 head per household (Thapa & Devkota 2003), comprised of yaks, a yak/cattle cross breed, sheep and horses. Herders use semi-permanent or temporary summer houses constructed in different sub-pastures (at 3600–4300 m) as shelters during the herding season (April–August). The livestock are grazed in the surrounding sub-pastures and brought back to summer houses every evening. However, male yaks and horses can range as far up as the highest alpine zone (>4500 m), and are brought back on special occasions and during winter.

Sampling

Vegetation sampling was conducted in summer pastures during the peak growing season (June/July) in 2000, and covered an area of approximately 75 km². Sampling was stratified in order to take into account the variation in topography (altitude and aspect) and the pattern and intensity

Table 1 Topographic and vegetation characteristics of the five pasture types. For altitude and slope, mean (\pm SD) and range are given.

Pasture type	Topographic characteristics			Vegetation structure
	Altitude (m)	Slope ^(o)	Aspect	
Moist sub-alpine meadows (MSAM)	3737 \pm 66 (3600–3900)	32.8 \pm 6.4 (24–40)	W–SW	Herb and grass meadows
Dry sub-alpine meadows (DSAM)	3945 \pm 51 (3850–4000)	26.5 \pm 5.9 (17–35)	E–SE	Herb and grass meadows
Moist alpine meadows (MAM)	4283 \pm 98 (4200–4400)	37.5 \pm 9.9 (22.2–46.4)	W–SW	Herb and grass meadows
Dry alpine meadows (DAM)	4405 \pm 90 (4300–4600)	42.4 \pm 7.7 (29–49)	W–SW	Herb and grass meadows
Moist alpine shrub pasture (MASP)	4243 \pm 186 (4000–4300)	34.7 \pm 8.8 (14–49)	N–NW	Shrub-dominated pasture

of human resource use. Firstly, we selected five types of pastures varying in altitude and aspect, namely sub-alpine meadows on moist W–SW-facing and dry E–SE-facing slopes, alpine meadows on moist W–SW-facing and dry E–SE-facing slopes, and shrub-dominated alpine pastures on moist N–NW-facing slopes (Table 1).

In pastures of each of these five categories, six sites were selected at increasing distances from the nearest semi-permanent summer house to provide a spatial gradient from highest human use pressure, in pastures located in the immediate surroundings of the summer houses (0.3–1 km), to moderate pressure at intermediate distance (>1–3 km) and least pressure in the pastures furthest away (>3 km). Several studies have shown a spatial gradient of human-induced pressure based on the distance from summer farms (for example Riginos & Hoffman 2003; Vandvik & Birks 2004). The spatial gradient extending from summer house to surrounding vegetation corresponded in our study area to a gradient of decreasing grazing pressure. For a majority of people, who stay in summer pasture with livestock, MP harvesting is also one of the important side activities and is related to livestock movement. However, intensity of MP harvesting by commercial collectors, and by most of the traditional healers, does not follow this gradient, as these specialists exploit different sites depending mainly on the quality and/or quantity of MP available (Ghimire *et al.* 2004). Vegetation composition in the three distance categories within each pasture type is presented in Appendix 1 (see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm).

At each site, five sampling transects (1 \times 10 m), each consisting of a line of ten contiguous 1 \times 1 m quadrats, were placed haphazardly and >50 m apart from each other. In all, a total of 150 transects (1500 quadrats) were studied. In each 1 m \times 1 m quadrat, we enumerated all the vascular plant species present and visually estimated the proportion of the quadrat covered by each species. Based on these data, mean cover-abundance was calculated for each distance category in each pasture type, considering only those quadrats in which the plant occurred. In each quadrat, we also visually recorded relative cover for bare ground and for four functional groups, namely mosses, graminoids, herbs (including herbaceous dicots, ferns

and non-graminoid monocots) and woody plants (shrubs). Relative cover of all functional groups and of bare ground added together represented 100% cover per quadrat. The frequency of each plant species in a transect was defined as the proportion of the transect's 10 quadrats in which it occurred.

Vascular plant species encountered in each quadrat were evaluated for their medicinal value on the basis of information gathered locally. Forty-eight people, including five traditional healers, were interviewed. We asked each person for the local name and medicinal uses of each species. A species was considered medicinal if more than five persons independently confirmed its medicinal uses (details in Ghimire *et al.* 2001 and Lama *et al.* 2001). We analysed the number of regionally rare (including species endemic to Nepal) and commercially threatened medicinal plants (CTMP) present in each transect. Designations of species as rare and threatened were based on Shrestha and Joshi (1996), Lama *et al.* (2001) and Tandon *et al.* (2001). Nomenclature follows Press *et al.* (2000). Vouchers were deposited at Tribhuvan University Central Herbarium (TUCH).

Environmental and human-impact variables

All the variables used in the present study are given in Appendix 2 (see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). Altitude, slope, aspect and geographical position were recorded at each transect. Slope, aspect and latitude were combined to estimate potential annual direct incident radiation (hereafter 'radiation') (McCune & Keon 2002). Soil samples from the top 20-cm layer were taken from 3–5 randomly chosen locations in each transect. Soil samples from each transect were combined and a sub-sample was taken for further analysis. The samples were analysed for pH (in soil:water suspension, 1:1 w/v) and organic matter (OM, Walkley-Black method).

The history of different pastures in terms of grazing, MP use and social management system was known from our previous studies (Lama *et al.* 2001; Aumeeruddy-Thomas *et al.* 2004). These gave data on distance of each site from the nearest summer house, and provided a basis for recording the intensity of grazing and harvesting of MP in each transect. Grazing intensity was evaluated as (1) low, (2) moderate or

(3) high, based on abundance of dung, signs of browsing or trampling, and livestock density. Intensity of MP harvesting was also assigned similar categorical values, by evaluating evidence of harvesting and the purpose (local use versus trade) of harvesting.

Data analysis

The relationships between environmental variables were assessed using Spearman rank correlations. All the variables related to human pressure (grazing, MP harvesting and distance to summer house) were combined to give an overall measure of human impact, referred to hereafter as combined human-impact variable (Him-PCA) using principal component analysis (PCA). Him-PCA was then used as a predictor variable in multivariate and regression analyses (see below). We also tested each variable separately. Detrended correspondence analysis (DCA) was performed in PC-ORD 4.25 (McCune & Mefford 1999) on the species cover-abundance data to interpret gradients in vegetation composition. Kendall correlation coefficients were calculated between scores of samples on DCA-axes and selected variables.

Species richness here is defined as the number of species per 10 m² transect. The total number of species across all transects for each site and for each of the five pasture types was calculated separately as a measure of gamma diversity (Whittaker 1972). Heterogeneity was measured as the mean dissimilarity (based on Sorensen distance) in species composition among transects within each site in each pasture type (McCune & Grace 2002). Differences in species diversity among pasture types were tested by one-way ANOVA.

The relationships between MP species richness, human-use patterns and other environmental variables in the entire data set were determined by fitting generalized linear models (GLM), using Poisson errors and a logarithmic link (McCullagh & Nelder 1989). Following Vetaas (1997), we used a forward stepwise method. First, we treated each of the environmental variables individually. Then only those variables that showed a significant change in deviance from the univariate regression were selected and fitted in the multivariate regression. In the step-wise multivariate regression we first fitted the variable that showed the highest significant change in deviance, then the variable leading to the next largest change, and so on. This procedure was continued until no further variable caused a significant reduction in deviance (Vetaas 1997). Multivariate regressions (same procedure) were also used to test whether the relationship between MP species richness and the combined human-impact variable (Him-PCA) would be significant after accounting for the effects of other significant variables not related to human impact. Sample scores on DCA axes were also used in multiple regressions to account for other unknown environmental gradients captured by DCA (Bhattarai *et al.* 2004).

To assess how individual MP species were affected by human influences, we characterized each species on the basis of its observed distribution of frequencies in transects compared

to the expected distribution, using chi-square tests (Roovers *et al.* 2004). For this purpose, transects were grouped together into three distance categories, namely (1) transects occurring near summer houses (<1 km), (2) at intermediate distances (>1–3 km), and (3) far from summer houses (>3–4.5 km). We categorized individual species that occurred in more than one of the distance categories in five response types: (1) 'increasers' (species with highest frequency of occurrence at closest distance); (2) 'decreasers' (lowest frequency at closest distance or highest frequency at furthest distance); (3) intermediates (highest frequency at intermediate distance); (4) extreme pattern (higher frequency at closest and furthest distances, but low at intermediate distance); and (5) no clear pattern (Landsberg *et al.* 2003).

RESULTS

Environmental and human-impact variables

Grazing and MP harvesting intensities were negatively correlated with altitude and the distance variable, indicating higher human pressure at lower altitude and close to summer houses (Appendix 2, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). The frequency of human impact, however, differed among pasture categories ($\chi^2 = 23.5$ and 34.3 for grazing and harvesting intensities respectively; $df = 2$, $p < 0.05$; Fig. 1). A high proportion of transects in dry alpine meadows showed low levels of human impact, while the majority of transects in sub-alpine meadows showed signs of moderate human impact. Soil OM was negatively correlated with both the distance variable and altitude, while pH increased with increasing slope, altitude and radiation. Among vegetation variables, the cover of graminoids decreased with decreasing distance from

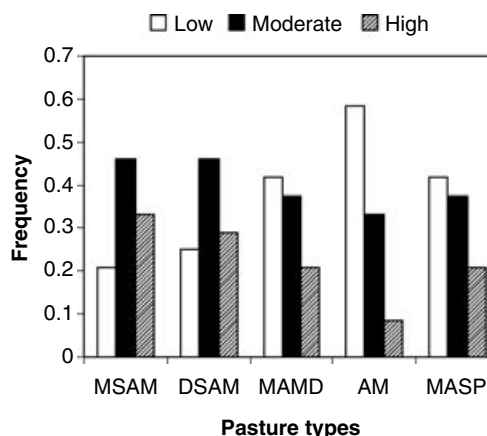


Figure 1 Frequency of different classes of intensity of human impact (mean of grazing and harvesting intensity) in different pasture types. MSAM = moist sub-alpine meadows, DSAM = dry sub-alpine meadows, MAM = moist alpine meadows, DAM = dry alpine meadows and MASP = moist alpine shrub pasture.

Table 2 Total number of species at the site and pasture levels ($n = 30$), species richness at the level of 10 m² transects ($n = 150$), and mean Sorensen distance among transects in five pasture types ($n = 30$), mean \pm SD. MSAM = moist sub-alpine meadows, DSAM = dry sub-alpine meadows, MAM = moist alpine meadows, DAM = dry alpine meadows and MASP = moist alpine shrub pasture. Means in each row with same superscript letters are not significantly different at $p = 0.05$, according to a one-way ANOVA with Tukey multiple comparison tests.

Diversity measures	MSAM	DSAM	MAM	DAM	MASP
Total all species (pasture level)	74	115	63	57	64
Total MP species (pasture level)	50	80	40	36	38
Total rare and CTMP species (pasture level)	11	15	7	4	10
Ratio MP:all (pasture level)	0.68	0.70	0.63	0.63	0.58
Total all species (site level)	33.2 \pm 6.5 ^a	39.0 \pm 10.8 ^b	27.2 \pm 10.5 ^a	27.0 \pm 6.5 ^a	24.3 \pm 6.5 ^a
Total MP species (site level)	19.7 \pm 4.0 ^a	26.5 \pm 8.5 ^b	15.7 \pm 6.9 ^a	17.8 \pm 7.2 ^a	14.0 \pm 3.9 ^a
Richness all species (10 m ²)	20.6 \pm 5.4 ^a	22.2 \pm 6.2 ^a	16.6 \pm 4.8 ^b	16.8 \pm 3.7 ^b	16.1 \pm 3.7 ^b
Richness MP species (10 m ²)	11.5 \pm 3.5 ^{ad}	15.3 \pm 4.8 ^b	9.5 \pm 4.1 ^{cd}	10.7 \pm 3.7 ^d	9.3 \pm 2.3 ^{cd}
Richness rare and CTMP species (10 m ²)	2.7 \pm 0.8 ^a	3.0 \pm 1.2 ^a	1.7 \pm 0.8 ^b	1.8 \pm 0.8 ^b	1.7 \pm 0.9 ^b
Sorensen distance	0.39 \pm 0.07 ^a	0.41 \pm 0.08 ^b	0.32 \pm 0.12 ^a	0.37 \pm 0.10 ^a	0.29 \pm 0.06 ^c

summer houses, whereas bare ground cover increased at sites close to summer houses.

Vegetation composition in relation to environment

Heterogeneity, measured as the mean dissimilarity in species composition among transects, showed highest values for sub-alpine meadows. Shrub-dominated alpine pastures showed lowest dissimilarity in species composition (Table 2). DCA ordination (Fig. 2a) showed a strong gradient separating samples from dry and moist pastures along axis 1 (eigenvalue 0.54; gradient length 3.97). This axis was correlated positively with moss cover and negatively with radiation and soil pH (Appendix 3, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). Along this axis most of the shrub-dominated pasture transects formed a distinct cluster at the positive end, suggesting that species composition in shrub-dominated pastures was less variable than in meadows, which formed more scattered groups. DCA axis 2 (eigenvalue 0.45; gradient length 3.16) reflected altitudinal, edaphic and disturbance gradients, separating meadow samples at high altitude and with low soil OM from samples occurring at lower altitude and with high soil OM.

Distributions of many MP species were associated with a particular environmental gradient and pasture type (Fig. 2b). Most of the MP species showing greater association with high altitude but less disturbed habitats were perennial herbs, including some rare and CTMP species (*Corydalis megacalyx*, *Cremanthodium purpureifolium*, *Delphinium brunonianum*, *Nardostachys grandiflora* and *Oxytropis williamsii*). Very few MP species showed strong association with moist and shady habitats. The majority of MP species, including rare and CTMP species, were associated with exposed slopes and lower-altitude habitats (Fig. 2b). In addition to rare and CTMP species, several common grazing-resistant MP species, such as *Elsholtzia eriostachya*, *Euphorbia stracheyi* and *Ligularia virgaurea*, and some widespread species, including *Geranium pratense* and *Rumex nepalensis*, showed a strong association with nutrient-rich, low altitude and

disturbed habitats (Fig. 2b). In addition, dominance in meadows of shrubs that tend to invade overgrazed sites (for example *Potentilla fruticosa*, *Rhododendron* spp. and *Salix calyculata*) also tended to be greater in sites close to summer houses (Appendix 1, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm).

Patterns of species diversity: local and landscape levels

A total of 179 species were represented in the samples, of which 118 (66%) were found to have medicinal uses (Appendix 4, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). Herbaceous perennials accounted for the largest proportion of all species (71.5%), followed by annual, biennial and a few longer-lived monocarpic herbs (12.3%). Shrubs accounted for 10.1% of total species, and graminoids for 4.5%. The majority of MP species (56 of 118) were Himalayan endemics (including six species endemic to Nepal) (Dobremez *et al.* 1967–2003). The second largest group was represented by species with SE Chinese (39 species) affinities. Five MP species had very broad geographical distributions (Holarctic).

Values of mean species richness per 10 m² transect for all vascular plants and for MP were 18.4 (range 8–37) and 11.3 (range 3–27), respectively. Total numbers of plant species at pasture and site levels, and species richness in 10 m² transects, were all highest for sub-alpine meadows, followed by alpine meadows (Table 2). Species richness in shrub-dominated alpine pastures was comparable to that in alpine meadows. The samples included 16 regionally rare and eight CTMP species, with a mean of 2.2 (range 0–5) such species per transect. The richness of rare and CTMP species showed positive correlations with richness of all plant species ($r = 0.60$, $p < 0.001$) and all MP species ($r = 0.61$, $p < 0.001$), and was highest in the species-rich sub-alpine meadows (Table 2).

About 40% of the 118 MP species were recorded from only one of the five types of pasture; 33% were shared among two types of pasture and the remaining 27% were shared among

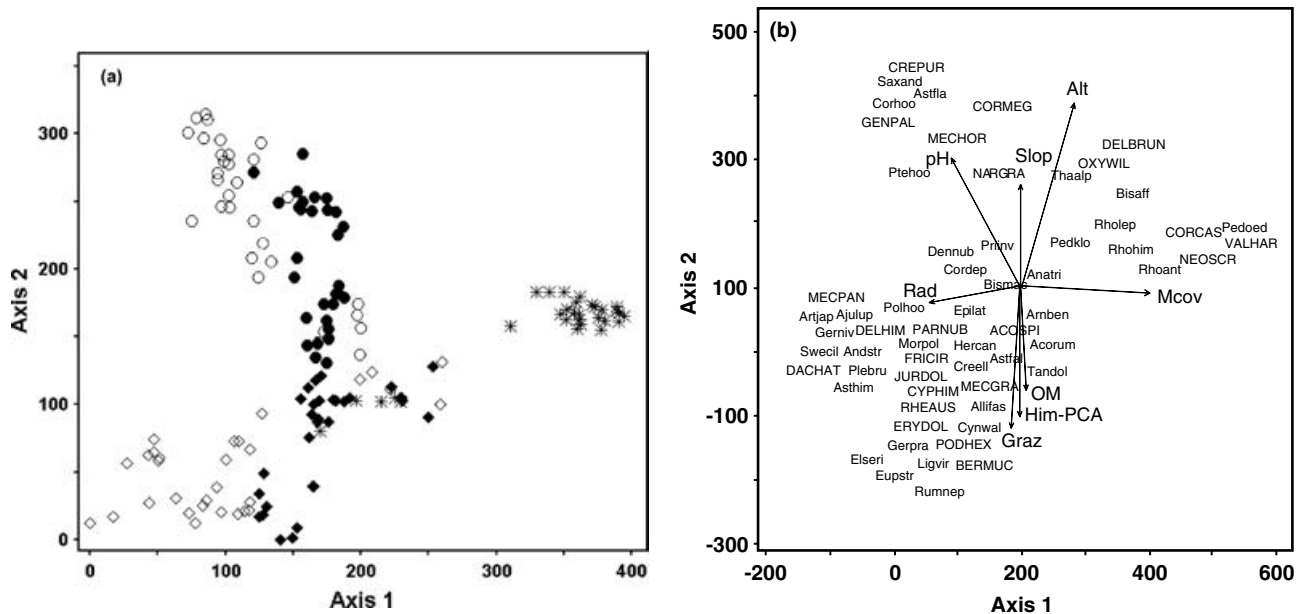


Figure 2 DCA ordination showing: (a) position of samples (150 transects), and (b) species scores. The first two DCA axes cumulatively explained 28.5 and 51.1% of variation in species data. In (a) sample scores are the weighted mean species scores; symbols refer to five pasture categories (\diamond = dry sub-alpine meadows; \blacklozenge = moist sub-alpine meadows; \square = dry alpine meadows; \blacksquare = moist alpine meadows; $*$ = shrub-dominated alpine pasture). In (b) environmental variables significantly correlated with at least one ordination axis are shown as biplot vectors (Kendall correlation, $p < 0.05$), altitude (Alt), slope (Slop), soil pH (pH), radiation (Rad), soil organic matter (OM), moss cover (Mcov), grazing intensity (Graz) and combined human-impact variable (Him-PCA). Species scores are shown for MP species with frequency $>10\%$ in any of the pasture categories (normal letters) and regionally rare and commercially threatened medicinal plant species (all capital letters). The species abbreviations presented in this figure are derived from the first three letters of the generic name followed by the first three letters of the specific epithet. The names of the species are: *Aconitum spicatum*, *Aconogonum rumicifolium*, *Ajuga lupulina*, *Allium fasciculatum*, *Anaphalis triplinervis*, *Androsace strigillosa*, *Arnebia benthamii*, *Artemisia japonica*, *Aster falconeri*, *A. flaccidus*, *A. himalaicus*, *Berberis mucrifolia*, *Bistorta affinis*, *B. macrophylla*, *Cortia depressa*, *Cortiella hookeri*, *Corydalis cashmeriana*, *C. megacalyx*, *Cremanthodium ellisii*, *C. purpureifolium*, *Cynoglossum wallichii*, *Cypripedium himalaicum*, *Dactylorhiza hatagirea*, *Delphinium brunonianum*, *D. himalayai*, *Dendranthema nubigenum*, *Elsholtzia eriostachya*, *Epilobium latifolium*, *Erysimum dolpoense*, *Euphorbia stracheyi*, *Fritillaria cirrhosa*, *Gentianopsis paludosa*, *Geranium pretense*, *Gerbera nivea*, *Heracleum candicans*, *Jurinea dolomiaea*, *Ligularia virgaurea*, *Meconopsis grandis*, *M. horridula*, *M. paniculata*, *Morina polyphylla*, *Nardostachys grandiflora*, *Neopicrorhiza scrophulariiflora*, *Oxytropis williamsii*, *Parnassia nubicola*, *Pedicularis klotzschii*, *P. oederi*, *Pleurospermum brunosis*, *Podophyllum hexandrum*, *Polygonatum hookeri*, *Primula involucreta*, *Pterocarpus hookeri*, *Rheum australe*, *Rhodiola himalensis*, *Rhododendron anthopogon*, *R. lepidotum*, *Rumex nepalensis*, *Saxifraga andersonii*, *Swertia ciliata*, *Tanacetum dolichophyllum*, *Thalictrum alpinum* and *Valeriana hardwickii*.

three or more types of pasture. Dry sub-alpine meadows showed the highest number of species found exclusively in one pasture type, followed by dry alpine meadows, moist sub-alpine meadows, shrub-dominated alpine pastures and moist alpine meadows (Table 3). Sub-alpine meadows also shared a number of MP species having alpine distribution (for example *Aster himalaicus*, *Cortia depressa*, *Lloydia longiscapa* and *Taraxacum tibetanum*) as well as species from lower-altitude habitats (for example *Artemisia dubia*, *Artemisia japonica*, *Asparagus filicinus*, *Parochetus communis*, *Plantago erosa* and *Roscoeia purpurea*).

Environmental variables and MP species richness

Many environmental variables showed significant relationships with MP species richness, but varied greatly in the amount of variation they explained (Table 4). Richness of

Table 3 Number of all species and MP species exclusively found in a particular pasture type (numbers in bold), and number of species shared among different pasture types. MP species are given in parentheses. MSAM = Moist sub-alpine meadows, DSAM = dry sub-alpine meadows, MAM = moist alpine meadows, DAM = dry alpine meadows and MASP = moist alpine shrub pasture.

	MSAM	DSAM	MAM	DAM	MAASP
MSAM	11 (7)				
DSAM	59 (40)	34 (23)			
MAM	25 (15)	38 (27)	5 (3)		
DAM	18 (9)	23 (15)	39 (24)	14 (9)	
MAASP	33 (17)	44 (26)	31 (19)	22 (15)	9 (5)

all MP species and of rare and CTMP species exhibited similar responses to most of the variables. Altitude and Him-PCA explained the highest proportions of deviance in

Table 4 Relationships between MP species richness (of all MP species and of rare and CTMP species) and predictor variables, based on GLM regression: (A) regression statistics of individual predictor variables; (B) multiple regression statistics based on a stepwise forward selection procedure. Polynomial first order (1) and second order (2) were tested against the null model. The deviation explained indicates percentage of total (null) deviance. *df* = degree of freedom; *p* = probability in chi-square test; ns = explained deviance is not significant. HIM-PCA = combined human-impact variable. Distance to summer house, harvesting intensity and grazing intensities were reduced to an overall measure of human impact by extracting them in one principal component through principal component analysis. The PCA axis showed an eigenvalue greater than one and explained 78% of the variance in the human-impact variables.

Predictor variables	Polynomial order	df	All MP species		Rare and CTMP species	
			% deviance explained	p	% deviance explained	p
(A) Univariate regression						
Distance	2	147	25	<0.001	16	0.003
Grazing	2	147	11	<0.001	19	<0.001
Harvesting	1	148	19	<0.001	22	<0.001
Him-PCA	2	147	33	<0.001	23	<0.001
Altitude (Alt)	2	147	24	<0.001	28	<0.001
Slope	1	148	2	0.029	–	ns
Radiation (Rad)	1	148	17	<0.001	14	0.005
Soil pH	1	148	19	<0.001	–	ns
Herb cover	2	147	18	<0.001	10	0.018
Graminoid cover	1	148	3	0.009	7	0.018
Shrub cover	2	147	8	<0.001	13	0.007
Total vegetation cover	2	147	4	0.005	–	ns
(B) Multiple regression						
Him-PCA + (Him-PCA) ²		147	31	<0.001		
+ Alt + (Alt) ²		145	11	0.002		
+ Rad		144	12	<0.001		
Alt + (Alt) ²		147			30	<0.001
+ Him-PCA + (Him-PCA) ²		145			10	0.032

species richness. Among individual human-impact variables, harvesting intensity was more clearly related to MP species richness than was grazing intensity. Univariate regressions showed that richness of all MP species and of rare and CTMP species had unimodal (hump-shaped) responses to altitude, and to most of the human-impact variables (except harvesting intensity). Harvesting intensity showed a significant negative linear relationship with species richness of these plants. MP species richness was highest at 3900–4000 m, with lower richness at altitudes lower and higher than this (Fig. 3). Areas closest to a summer house and under the highest grazing pressure, as well as areas most distant from a summer house and least affected by grazing, had lower MP species richness than areas at intermediate (1–3 km) distance from the nearest summer house (Fig. 3). Increase of radiation was positively correlated with the richness of all MP species and of rare and CTMP species (Table 4; Fig. 3). Among edaphic factors, pH seemed to be important only in the case of total MP species richness, which was positively correlated with pH (Table 4).

Although univariate regressions were significant for most of the variables, only altitude and Him-PCA were capable of predicting variation in richness of rare and CTMP species in multiple regressions (Table 5). In addition to these, radiation also showed a significant contribution to explaining total

MP species richness. Total MP species richness showed a significant unimodal (hump-shaped) relation with Him-PCA when the latter was added to the model after the first and second order polynomials of altitude, radiation or DCA-axis score (Table 5). For rare and CTMP species, this relationship was not evident after accounting for other factors. Based on their contribution to the total (null) deviance, sample scores on the first DCA axis accounted for about 16% of the variation in CTMP species richness and about 25% of variation in MP species richness (Table 5). This indicates that the main floristic gradients are also gradients in MP species richness. MP species richness decreased linearly from samples showing lowest scores along the first axis to samples showing highest scores.

Frequency and cover-abundance of medicinal plant species

About 90% of all MP species occurred in fewer than 10% of all quadrats (Table 6 and Appendix 4, see Supplementary material at http://www.ncl.ac.uk/iccf/EC_Supplement.htm). Cover-abundance data also showed similar patterns (Table 6). The 118 MP species recorded in the study were classified into eight groups, based on their frequency of occurrence as a function of distance from the nearest summer

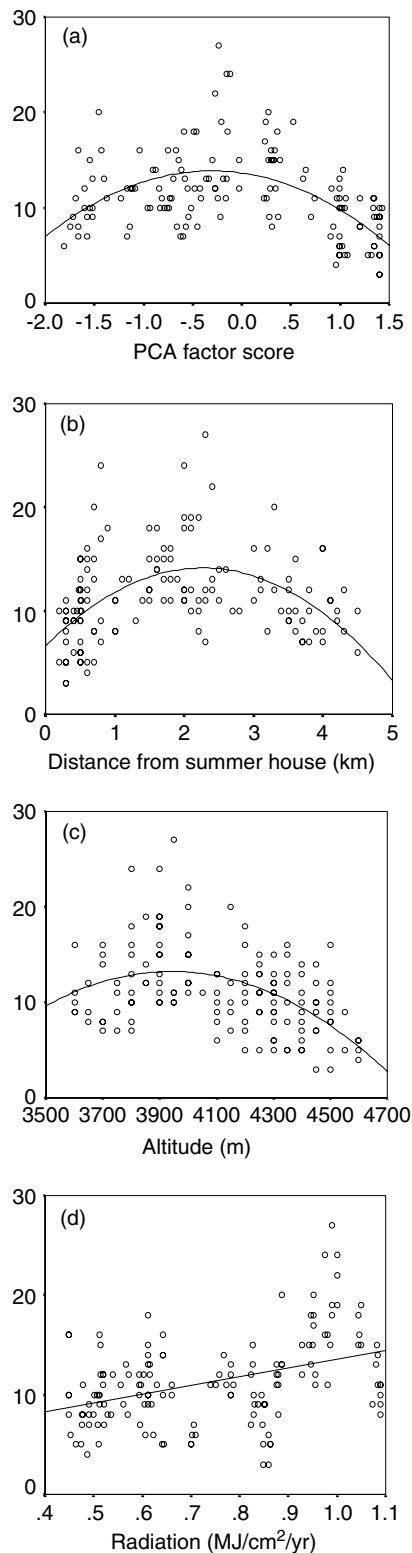


Figure 3 Scatter plots of total MP species richness in relation to selected variables: (a) PCA factor score representing combined measure of human pressure (Him-PCA); (b) distance from the nearest summer house; (c) altitude; and (d) radiation. The y-axis represents species richness at the level of 10-m² transects. The regression line was fitted based on first or second order polynomial regression using generalized linear models.

house (used here as a surrogate for human impact). In general, cover-abundance showed patterns similar to frequency. Groups that decreased in frequency (and cover-abundance) with increasing proximity to summer houses ('decreasers'), that increased near to summer houses ('increasers') and that were most frequent at intermediate distance were represented by 31, 31 and 34 species, respectively. Similarly, more or less equal numbers of MP species (7, 5 and 6, respectively) showed distributions restricted to only one of the three distance categories. Two species showed no significant pattern, and two further species had high frequency both near the summer house as well as at furthest sites ('Ext' pattern, Appendix 4, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). Most of the species showing greater frequency and cover-abundance close to summer houses, or even restricted to such sites, were grazing-resistant. Some of them, such as *Anaphalis triplinervis* var. *monocephala* and *Bistorta macrophylla*, were dominants in these sites (Appendix 4, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). All the five geographically widespread species were 'increasers'. About 68% of 'decreasers' showed mean frequency less than 2%. Higher proportions of the species classified as 'increasers' (56%) and intermediates (53%), however, showed mean frequencies >2%. For abundance, an even higher proportion of 'decreaser' species (74%) was in the low abundance group (<2%) (Table 6).

Most of the rare MP species (for example *Corydalis cashmeriana*, *Fritillaria cirrhosa*, *Gentianopsis paludosa* and *Meconopsis horridula*), two species endemic to Nepal (*Corydalis megacalyx* and *Erysimum dolpoense*) and three CTMP (*Dactylorhiza hatagirea*, *Nardostachys grandiflora* and *Neopicrohiza scrophulariiflora*), were most abundant at sites furthest from summer houses. Other species showed different trends. Other rare and/or CTMPs, such as *Aconitum spicatum*, *Meconopsis paniculata*, *Jurinea dolomiaea* and *Podophyllum hexandrum*, were abundant even close to summer houses, and *Arnebia benthamii*, *Delphinium himalayai*, *Meconopsis grandis*, *Oxytropis williamsii* and *Rheum australe* were most abundant at intermediate distances from summer houses. Thus grazing intensity, which is highly correlated with distance to summer houses, affects different rare and CTMP species in different ways.

DISCUSSION

Vegetation composition and distribution of MP

Spatial gradients in environmental variables and species composition occurred with distance from summer houses, as in other grassland studies (for example Vandvik & Birks 2004). However, in meadows, species composition was highly variable along the disturbance gradient, as compared to shrub-dominated pastures (Appendix 1, see Supplementary material at http://www.ncl.ac.uk/icef/EC_Supplement.htm). Sites closest to summer houses showed high abundance of perennial

Table 5 Effect of the combined human-impact variable (Him-PCA) on richness of MP species and of rare and CTMP species after accounting for altitude (Alt), radiation (Rad) and DCA axis scores. Polynomial GLM regression was used. Res Dev = residual deviance; p = probability in chi-square test; ns = explained deviance is not significant.

<i>Variables</i>	<i>df</i>	<i>Total MP species</i>		<i>Rare and CTMP species</i>	
		<i>Res Dev</i>	<i>p</i>	<i>Res Dev</i>	<i>p</i>
<i>Accounting for altitude</i>					
Null	149	240.3		75.7	
Alt	148	208.2	<0.001	56.0	<0.001
+ (Alt) ²	147	182.4	<0.001	54.7	ns
+ Him-PCA	146	155.7	<0.001	46.3	0.004
+ (Him-PCA) ²	145	135.0	<0.001	45.5	ns
<i>Accounting for radiation</i>					
Null	149	240.3		75.7	
Rad	148	199.9	<0.001	64.9	0.005
+ (Rad) ²	147	200.4	ns	72.4	ns
+ Him-PCA	146	151.6	<0.001	57.3	0.006
+ (Him-PCA) ²	145	111.9	<0.001	51.9	0.020
<i>Accounting for DCA 1</i>					
Null	149	240.3		75.7	
DCA1	148	181.2	<0.001	63.7	<0.001
+ (DCA1) ²	147	172.5	0.003	63.7	ns
+ Him-PCA	146	159.0	<0.001	58.9	0.028
+ (Him-PCA) ²	145	133.5	<0.001	55.5	ns
<i>Accounting for DCA 2</i>					
Null	149	240.3		75.7	
DCA2	148	224.5	<0.001	62.6	<0.001
+ (DCA2) ²	147	171.7	<0.001	59.7	ns
+ Him-PCA	146	147.5	<0.001	48.7	<0.001
+ (Him-PCA) ²	145	126.0	<0.001	47.0	ns

Table 6 Percentage of medicinal plant species (data from all transects) in each category of response to human impact (in terms of distance from a summer house), sorted into three classes (>10%, > 2–< 10% and <2%) of frequency or cover-abundance. F = frequency of occurrence (% of quadrats in which the species occurred); A = cover-abundance (mean % cover accounted for by the species).

Frequency or cover-abundance classes	Decreasers		Increasers		Intermediates		All MP species	
	F	A	F	A	F	A	F	A
>10%	5	5	14	14	8	5	8	8
>2–<10%	26	21	42	39	45	40	38	33
<2%	68	74	44	47	48	55	53	58

herbaceous species, many of which spread in response to extensive grazing (Miehe 1997). Furthermore, in certain disturbed areas, nitrophilous species (for example *Elsholtzia eriostachya* and *Rumex nepalensis*) showed high frequency at sites with high levels of nitrogen from animal droppings. However, such areas are often found only very near to summer houses, where livestock stay overnight. In shrub-dominated pastures, low light availability due to the shrub canopy prevented occupation by light-demanding herbaceous species, of which only few species were present per transect. These were a more homogeneous group than those in meadows. Meadow transects had larger numbers of plant species and higher inter-sample variance. The MP species which were particularly confined to such shady habitats were *Neopicrorhiza scrophulariiflora*, *Pedicularis oederi* and *Valeriana hardwickii*.

Many MP, including rare and CTMP, showed associations with high radiation and with lower-altitude meadow habitats. Steep E–SE-facing slopes are the sites most exposed to radiation in such meadows and thus provide favourable habitats for many rare and CTMP species. In the Himalaya, exposed E–SE-facing slopes are generally not fully snow-protected during winter, in contrast to the shady N–NW-facing slopes. The latter slopes are thus often occupied by drought-sensitive evergreen shrubs (Miehe 1997).

MP species richness and environmental variables

Richness of all MP, including CTMP species, responded similarly to most of the environmental variables. However, Him-PCA was significantly negatively correlated with richness of rare and CTMP species, after other environmental

factors were accounted for in stepwise regressions. McIntyre and Lavorel (1994) also found that richness of rare species responded to environmental variables in a similar manner to common native species, but that rare species were more sensitive to factors reducing species richness.

This study found highest species richness at intermediate levels of disturbance. Other studies from grassland habitats have also reported higher species richness at intermediate levels of grazing and low richness, at no grazing or at high grazing pressure (for example Milchunas *et al.* 1988; McIntyre *et al.* 2003), and several explanations have been suggested for this relationship (Huston 1979; Milchunas *et al.* 1988). In the present study, the lower MP species richness at sites closest to a summer house may be attributed to the elimination of sensitive species due to heavy grazing and effects of trampling. Some of the sensitive MP are *Corydalis cashmeriana*, *Cremanthodium ellisii*, *Cypripedium himalaicum*, *Dactylorhiza hatagirea* and *Erysimum dolpoense*. At furthest distance, a few species (mainly graminoids, for example *Kobresia nepalensis*) with strong competitive ability may have excluded less competitive species. This latter hypothesis is supported by the significant negative linear relationship between MP species richness and cover of graminoids (Table 4).

MP species richness also showed a unimodal (hump-backed) relationship with altitude, peaking at 3900–4000 m. This is higher than the estimates obtained by interpolation from elevational range data for all vascular plant species from the Nepal Himalaya (Grytnes & Vetaas 2002). However, Vetaas and Grytnes (2002) also reported a plateau in species richness around 3000–4000 m for vascular plants and 4000 m for endemic species, results comparable with ours. Among edaphic variables, pH showed a positive linear correlation with total MP species richness, but no significant correlation with richness of rare and CTMP species. Increase in species richness from acidic to neutral soils has been reported from other studies in semi-natural grassland (for example Austrheim *et al.* 1999). Other studies have also reported that rare species show significant responses to edaphic gradients (McIntyre & Lavorel 1994). In our study, the criteria used in defining rare and threatened species were different than those used by McIntyre and Lavorel (1994). Although all the six endemic MP species were included in the 'rare' category, most of the rare MP species are threatened by over-harvesting, and thus their response to human pressure was more pronounced than that to other factors.

Human-use patterns as a factor maintaining MP species richness at the landscape level

Among the five types of pastures studied, sub-alpine meadows showed the highest diversity of MP. Other studies (for example Kala *et al.* 2002) have also reported high plant species diversity in Himalayan sub-alpine landscapes. We found that sub-alpine meadows also included higher numbers of rare and CTMP species. Our finding is in agreement with other studies, which showed that high total species richness is a predictor for the occurrence of rare and vulnerable species

(for example Nilsson *et al.* 1988; McIntyre & Lavorel 1994; Austrheim *et al.* 1999).

Sub-alpine meadows, created and continuously influenced by human actions, thus appear particularly rich in MP species diversity. These grasslands are structured by complex interactions between natural processes and human management on different spatial and temporal scales (Schweinfurth 1983; Miede 1997). In such landscapes, resource management regimes related to rotational grazing practices and harvesting of resources are often based on different levels of socio-cultural controls, which can have a significant effect in creating heterogeneity and maintaining species diversity. The heterogeneity of these meadows is indicated by the high values of species dissimilarity (i.e. beta-diversity) among pasture types (Table 2). Processes at the landscape level are indicated by the presence of a large number of species restricted to a single pasture type (Table 3), and by the coexistence of species with alpine distribution and those found also in lowland habitats. Some of these species are considered to have increased in local abundance and regional distribution over a long period of human interaction with the landscape.

In high mountain regions, the upper limits of the distribution of plant species are set by climatic severity, short growing season and resource limitations (Körner 1999). The lower gamma diversity we observed in alpine meadows, compared to sub-alpine meadows, is consistent with the fact that alpine habitats have a limited species pool of vascular plants, mainly as a result of environmental constraints (Körner 1999; Austrheim 2002). Generally, alpine plants grow more slowly, have longer life spans and have a higher degree of vegetative reproduction than plants at lower altitude (Körner 1999). Thus, in alpine areas, the habitats created by human-induced factors may not be easily exploited by species of low abundance as at lower altitudes, but will be used by dominant species, possibly through vegetative reproduction (Körner 1999). Other explanations for the decrease in species richness at high altitude in the Himalaya take into account their insular nature, i.e. the decreased land area of each mountain with increasing elevation and the presence of barriers between patches of similar habitat (Vetaas & Grytnes 2002).

Grazing, to a certain extent, was found to favour MP species diversity at the expense of the abundance of palatable plants. Many MP species, mostly grazing-resistant ones, showed high abundance at sites closest to summer houses. Some of the species with increasing abundance closer to summer houses were shrubs. Invasion of grazed areas by shrubs creates vertical heterogeneity, providing a heterogeneous environment allowing coexistence of additional MP species. Thus, at the landscape level, the large number of species that increase under human use pressure (mainly grazing) compensates for the loss of 'decreasers' as the intensity of grazing increases, thus maintaining the overall pool of MP species diversity in this anthropogenic landscape. Along a grazing gradient in Australia, McIntyre *et al.* (2003)

also found that similar numbers of species increased with grazing (increasers) or declined with increasing grazing (decreasers).

Much work has been conducted on the social and political dimensions of forest-based agroecosystems, as well as on their importance in biodiversity management (see Michon 2005). No comparable work has been undertaken, however, in high-altitude agroecosystems. Socio-cultural dynamics, as analysed by different authors (for example Dollfus & Labbal 2003; Smadja 2003; Aumeeruddy-Thomas *et al.* 2004), show that pastures in alpine or sub-alpine areas of the Himalaya are appropriated symbolically and materially and are named and identified according to use patterns and tenure systems. Such landscapes in the Himalaya are often seen by the tenants of biodiversity conservation as natural wilderness areas which are threatened by man (see Wikramanayake *et al.* 2001). The mosaic of pastures and summer house settlements created by the differential use of species and land in space and time by different user groups introduces high levels of heterogeneity at species, community and landscape levels. High altitude pastures, associated fields and human settlements are thus rural landscapes rather than wilderness areas. Our analysis of factors affecting biodiversity in such landscapes shows that a large number of MP species are closely associated with single pasture types, and we find high values of species dissimilarity among pastures. Specific ethnoecological knowledge and management practices are related to spatial distribution and abundance of species (Ghimire *et al.* 2004). Similarly, forbs and grasses of interest to agro-pastoralists require a high level of management, incorporating the application of specific ethnobiological knowledge, rotations, and different systems of access and control in different pastures over time (Bauer 2004). The two resources highlighted in this paper, grazing resources and medicinal plants, are thus part of an overall complex rural agroecosystem. The importance for biodiversity conservation of such agrarian landscapes is fully acknowledged in other parts of the world (Pärt & Söderström 1999). In the Himalayas, such complex agroecosystems, and their linkages with biodiversity conservation, still need to be fully recognized. Policies that take into consideration the importance of human-related variables in generating diversity at different ecological levels are required for their environmental management.

CONCLUSIONS

Our results lead to five conclusions. (1) Human-use patterns have significant effects on the composition of high-altitude pasture vegetation and on diversity of MP species. (2) Sub-alpine meadows of the Himalayas are richer in MP species diversity than are alpine meadows. (3) Our data also support the idea that environmental factors predicting richness of rare species are largely the same as those predicting total richness. Thus, management to maximize total MP species

richness will also favour rare species. (4) Each kind of habitat is characterized by particular suites of MP species, and habitat diversity is partly due to differential human use. (5) MP species may be positively influenced, to a certain extent, by human-use pressure. The maintenance of diversity of MP, as well as that of other pasture resources, is critically dependent on defining management practices, including strategies for maintaining a level of grazing and resource harvesting that is both ecologically and economically sustainable. The two resources, namely forage for livestock and MP species for local health care, cannot be managed independently; a systems approach is needed, incorporating social management to accommodate the needs of different users at the landscape level. Different needs may not be accommodated in the same spaces, but in a mosaic of different spaces that enable the different types of resources to coexist.

The differential use of Himalayan landscapes by a diversity of users, each placing different values on different suites of resources, creates complexity and heterogeneity. This heterogeneity favours biodiversity at different ecological scales. In this case study, we show that ecosystem diversity and social diversity interact to produce diversity at the landscape level. Natural processes and use patterns combine to produce gradients in level of disturbance and in resource availability, and these two key variables influence species composition, richness and abundance. Social diversity is expressed by differential use patterns and values, as well as by particular practices associated with different suites of species and communities. The concept of biodiversity tends to carry a universal value at the global level, mostly associated with biological processes (Wilson & Peter 1988), yet the association of social values with the organization of biodiversity leads us to conceive of different 'biodiversities' determined by different social practices. From the point of view of conservation, rare, endemic and spectacular species are often ascribed more value. This raises the major question of what biodiversity to conserve and for whom. The high-elevation anthropogenic Himalayan landscapes function as a complex agroecosystem, which harbours not only rare, endemic species, but also more ordinary and widespread species. The environmental management of such landscapes, if it were to consider local human needs, knowledge and practices, as is promoted for instance by the Convention on Biological Diversity (CBD), should consider the management of all components and not only rare, endemic and spectacular species.

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