Journal of
Plant Ecology

VOLUME 1, NUMBER 2,
PAGES 117–136

JUNE 2008

doi: 10.1093/jpe/rtn012

available online at
www.jpe.oxfordjournals.org

Spatial patterns of plant diversity and communities in Alpine ecosystems of the Hengduan Mountains, northwest Yunnan, China

Ruth Sherman[1,*], *Renee Mullen*[2], *Li Haomin*[3], *Fang Zhendong*[4] *and Wang Yi*[5]

[1] *Department of Natural Resources, Cornell University, Ithaca, NY 14853, USA*
[2] *The Nature Conservancy, Boise, ID 83702, USA*
[3] *The Nature Conservancy, China Program, Kunming, Yunnan 650034, People's Republic of China*
[4] *Shangri-la Alpine Botanical Garden, Zhongdian, Yunnan, 674400, People's Republic of China*
[5] *Biology Department, Yunnan University, Kunming, Yunnan, 650091, People's Republic of China*
*Corresponding author: Department of Natural Resources, Cornell University, Ithaca, NY 14853, USA.
E-mail: res6@cornell.edu

Abstract

Aims

Conduct a quantitative, but rapid, regional-level assessment of the alpine flora across northwest Yunnan (NWY) to provide a broad-based understanding of local and regional patterns of the composition, diversity and health of alpine ecosystems across NWY.

Methods

A stratified random sampling design was employed to select sites across the different mountain ranges of NWY. Vegetation was sampled by stratifying each site by the three major alpine vegetation community types: meadow, dwarf shrub and scree. Two 50-m transects were randomly located within each community type at each sampling site with 10 1-m^2 subplots systematically placed along each transect. Environmental variables were recorded at each transect. Multivariate analyses were used to classify the major plant community assemblages and link community patterns to environmental and habitat variables.

Important Findings

Forb species richness varied from 19 to 105 species per site (21 sites total) with an average of 59 species per site (60 m^2 sampled per site). Most species were patchily distributed with narrow distributions and/or small population sizes; over half the species occurred at only one or two sites. Distinct species assemblages were identified in the meadow vegetation that was strongly aggregated by geographic location suggesting the presence of distinct phytogeographic zones of the meadow alpine flora. Elevation and geographic location were the dominant environmental gradients underlying the variations in species composition. Jaccard's coefficient of similarity averaged only 10% among sites indicating there was little similarity in the alpine flora across the region. The alpine vegetation is highly heterogeneous across the complex landscape of the Hengduan Mountains of NWY. Conservation strategies need to take into account the large geographic differences in the flora to maximize protection of biodiversity.

Keywords: biodiversity hotspot • community ecology • multivariate analysis • Yunnan Great Rivers Project (YGRP) • World Heritage Site

Received: 8 January 2008 Revised: 9 April 2008 Accepted: 15 April 2008

Introduction

The mountains of south-central China are one of the most biologically rich temperate regions on earth. This unique ecoregion represents one of the world's 26 hotspots of biodiversity (Mittermeier *et al.* 1999) and was recently designated a world natural heritage site. Within this hotspot lie the southern Hengduan Mountains of northwest Yunnan (NWY), the site of the Yunnan Great Rivers Project (YGRP), a collaborative effort between the Yunnan provincial government and The

Nature Conservancy (TNC) to conserve critical habitats and species (Ma *et al.* 2007). Owing to the extreme altitudinal variation, its location at a biogeographical convergence zone of temperate and tropical realms and a monsoonal climate, the YGRP area supports a wide range of ecosystems and vegetation types yielding the richest diversity of higher plants in China (Gaetz 2002; Guo and Long 1998; Tang *et al.* 2007).

The alpine zone, mountain areas located above tree line and below the permanent snow line (Byers 2005), was one of eight ecoregional conservation targets chosen by experts as the basis for the YGRP Ecoregional Assessment (Ma *et al.* 2007). The alpine habitat across the YGRP was classified as an important conservation priority because of its high species richness, high levels of endemic species, economic and cultural value to local communities and threat of species losses due to increasing land use pressures and climate change (Baker and Moseley 2007; Buntaine *et al.* 2007; Deng and Zhou 2004; Ma *et al.* 2007; Salick *et al.* 2004; Sherman *et al.* 2007; Xu and Wilkes 2003). However, conservation efforts in NWY have focused primarily on forest ecosystems while the alpine has been largely ignored due in part to the lack of data and limited understanding of these highland systems. In 2003, the TNC China initiated the Alpine Ecosystem Project as a collaborative effort between government, communities and research institutes to focus attention on, understand and conserve the alpine ecosystem across the YGRP (Ma *et al.* 2007; TNC 2006).

In order to establish regional conservation goals and develop strategies to achieve those goals, an understanding of how the diversity and composition of alpine communities varies among locations is critical for prioritizing conservation efforts. For example, if the species composition is similar among sites across the region, then the specific location of a nature reserve is not important relative to this factor. However, if there are large differences in the flora among geographic locations, then the selection of areas for protecting native plant species poses a much greater challenge to conservation managers. In Europe, the alpine flora is highly heterogeneous with only 3–25% of the alpine species shared among mountain ranges (Vare *et al.* 2003). In contrast, there is a high degree of similarity among the alpine floras of the Southern, Central and Northern Rocky Mountains of the USA with at least 50% of the species shared among provinces (Bowman and Damm 2002; Hadley 1987). Unfortunately, the alpine flora is not well studied in many parts of the world, especially in regions with high levels of biodiversity and endemism, and few generalizations can be made regarding geographic patterns of alpine plant diversity.

The elevational distribution of species richness, percent endemism and numbers of useful plants is greatest in the alpine meadows as compared to lower elevation ecosystems in NWY (Anderson *et al.* 2005; Salick *et al.* 2004). Thus, the alpine zone of NWY can be considered a hotspot of diversity within a global hotspot of biodiversity. However, there is a growing concern that the alpine in NWY is being degraded. The rapid pace of development and infusion of a market economy has resulted in changes in traditional grazing practices, increased harvesting of medicinal plants and increased tourism activities, all have which been implicated as growing threats to biodiversity in the region (Xu and Wilkes 2003). Because of these rapid socioeconomic changes, conservation managers feel a sense of urgency to implement conservation actions but lack the necessary information on which to make informed decisions. Hence, any efforts to protect alpine biodiversity and promote their sustainable use are seriously constrained by the limited understanding of these systems. The present study was undertaken as part of the Alpine Ecosystem Project (TNC 2006) to provide conservation planners with information on the distribution patterns of alpine plant species and communities across NWY as an initial step for prioritizing conservation efforts.

Although past inventories have documented the rich flora of the alpine in NWY (Guan *et al.* 1998; Guo and Long 1998), there has been no systematic sampling that allows for the analysis of or comparison among floras across the region. The goal of this study was to conduct a rapid but quantitative regional-level assessment of the alpine flora across NWY to provide a broad-based understanding of local and regional patterns of the alpine vegetation, a necessary first step for establishing conservation priorities in the region. Our specific objectives were the following: (i) determine how alpine plant species richness and composition vary across the mountains of NWY, (ii) examine relationships between alpine plant diversity and environmental parameters and (iii) assess the current health and status of the alpine with regard to human land use. A systematic sampling approach with equal sampling effort at randomly chosen alpine sites across NWY was employed to allow for the direct comparison of vegetation attributes among sites.

Study area

This study was conducted in the Hengduan Mountains (26–30°N) in the northwestern region of Yunnan in southwest China (Fig. 1). The Hengduan Mountains, oriented north-south along the eastern flanks of the Himalayas and southeast of the Qinghai Tibetan Plateau, have been identified as a hotspot for temperate biodiversity (Mittermeier *et al.* 1999), were recently designated the 'Three Parallel Rivers' Natural World Heritage Site (http://whc.unesco.org), and is the site of TNC's YGRP (http://www.nature.org). Three major Asian rivers, the Yangtze (Jinshajiang), Mekong (Lancangjiang) and Salween (Nujiang), have carved deep parallel gorges that run north to south through the high mountain ranges within a distance of 100 km of each other creating a spectacular landscape of glaciated peaks rising from 1000 m in the river valleys to the highest peak at 6740 m. The varied geology, topography and climate have combined to create this epicenter of biodiversity that the Chinese Academy of Sciences considers the most critical region for biodiversity conservation in the country (IUCN 2003).

The YGRP in NWY includes 15 counties and covers an area of ~ 69,000 km^2 bordered to the north-northwest by the

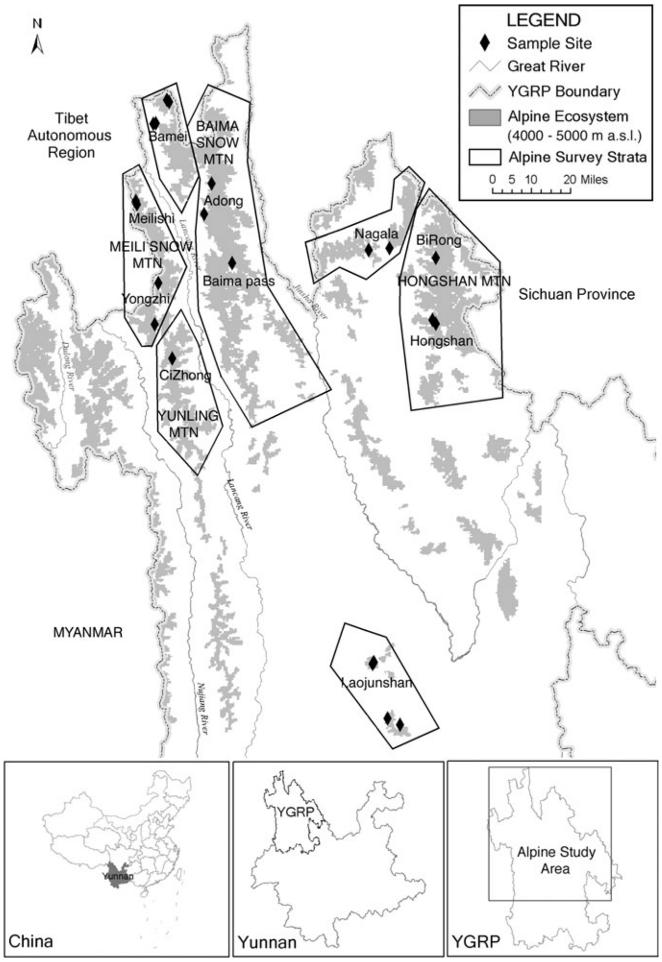

Figure 1 map showing the location of the YGRP in NWY, China. The diamonds represent the 21 alpine sampling sites, and the polygons represent the different strata used in the stratified random sampling design.

Tibetan Autonomous Region, Myanmar to the west and Sichuan Province to the east and northeast (Moseley 2006). The prevailing climate is monsoonal with wet summers and dry winters with most precipitation falling between June and September. There is a general trend of decreasing precipitation from the southeast to northwest but patterns vary considerably from location to location. The alpine zone is located between ~3800 and 5200 m and constitutes ~12% of this mountainous area. The alpine consists of three dominant community types: dwarf shrub (woody dominated communities), meadow (herbaceous-dominated communities with a developed soil substrate) and scree or talus (primarily herbaceous vegetation growing on a loose rock substrate). The alpine shrublands predominate at lower elevations of the alpine near tree line. Alpine meadows generally occur at higher elevations above the shrub communities followed by scree slopes. Permanent snow and ice occurs at ~5200 m elevation. The mean annual temperature >4100 m is <0°C.

Methods

Sampling strategy

A stratified random sampling design was used to inventory the vascular plants of the alpine ecosystems across NWY. The project area was stratified by geographic location with the major mountain ranges serving as the primary strata. A total of seven strata were delineated. The assumption for using these strata was that the vegetation would be more similar within a mountain range than between ranges. Within each stratum, five 1-km^2 sample sites were randomly selected using a 1-km^2 grid overlay of a map of the alpine (areas between 4000 and 5000 m elevation) of NWY.

In the field, each site was further stratified by the three major alpine vegetation community types: meadow, shrub and scree. Two transects were randomly located within each community type at each sampling site for a total of six sampling transects. Each transect was 50-m long, and ten 1-m^2 subplots were systematically placed along each transect at 5-m intervals to sample the vegetation. A total of 60 m^2 was sampled per site. Field surveys were carried out from June through mid-October 2005.

Species presence and foliar cover data for each vascular plant species (excluding grasses [Poaceae], sedges [Cyperaceae] and rushes [Juncaceae]) were quantified in each 1-m^2 subplot. Nine vegetation cover classes were used to quantify species in each subplot: <1.0, 1–2, 2–5, 5–10, 10–25, 25–50, 50–75, 75–95 and >95%. Also, the percentage of bareground (disturbed, open soil), graminoids (including grasses, sedges and rushes) and rock (the amount of exposed rock) that covered each sample plot was recorded using the same cover classes as above. Average height of the meadow vegetation also was recorded in each 1-m^2 subplot as a measure of vegetation structure. In addition to the vegetation data, plot site characteristics were measured at each transect. The transect location was recorded with a Global Positioning System (GPS) so that plots could be mapped and relocated for future measurements. Environmental data collected included elevation, slope gradient, aspect, terrain shape index (TSI: concave [1.0] to convex [−1.0]) (McNab 1989) and slope position (ridge top to valley bottom).

All species were described in the field and given a field identification number that was used throughout the field season, and specimens were collected for later identification. A total of 668 voucher specimens were collected. Specimens are housed at the Alpine Botanical Institute in Zhongdian, Yunnan, and were identified by Fang Zhendong, the Director of the Institute, and his staff.

Data analysis

The total number of species, genera and families were tallied for each site, and richness was compared among strata (sites as replicates within strata) using a Kruskall–Wallis test for k independent samples in S-Plus 6.2. Species accumulation curves were calculated for each site using EstimateS software (Colwell 2005) to compare theoretical and actual numbers of species recorded at each site as a means to assess the adequacy of our sampling methods.

Species richness of each community type (meadow, shrub, scree) was compared using a nested analysis of variance model (sites nested within strata) in S-Plus 6.2 with species richness per transect, i.e., the number of species in ten 1-m^2 plots along a 50-m transect, used as replicates. Levels of significance were compared using an analysis of unweighted means with Type III sums of squares to account for the unbalanced nature of the data and followed by a *post hoc* multiple comparison test using the multicomp function and best method option (S-Plus 6.2).

The relationships between environmental factors and species richness were investigated using generalized linear models with a Poisson distribution and the logit link function in S-PLUS (Crawley 2002). Separate regressions were constructed for each of the three different community types. Aspect, a circular variable, was converted into two linear variables: South.slope [cos(aspect) × sin(slope)] and East.slope [sin(aspect) × sin(slope)]. The variables South.slope and East.slope combine aspect and slope into one variable to generate a 'sun index' that is an indirect measure of the amount of solar radiation that a site receives (Gibson *et al.* 2004; Wilson *et al.* 2001). The sun index ranged from –1.0 to 1.0, with a value of 1.0 indicating due south or east on a steep slope and –1.0 indicating due north or west with a steep slope, respectively. Other predictor variables used in the analyses included slope, TSI, percent graminoid cover, bareground and rock cover. The best-fit model was assessed by comparing the residual deviance between models as parameters were added or removed using an *F* test (Crawley 2002).

Multivariate analyses were used to classify the major plant community assemblages and link community patterns to environmental and habitat variables. All multivariate analyses were performed using PC-ORD 4.0 (McCune and Mefford 1999). The foliar cover data were aggregated at the transect level, i.e., cover estimates of species averaged across the ten 1-m^2 plots, for all multivariate analyses. Uncommon species, those that occurred in less than or equal to two transects, were not included in the analyses. A total of 145 species were used in the analysis of the meadow communities, 138 species in the shrub and 110 species in the scree community analyses. Cluster analysis was applied to the vegetation data to combine transects with similar species into alpine community groups (McCune and Mefford 1999). The Sorensen (Bray-Curtis) index and group average linkage method were used to calculate species groupings (McCune and Mefford 1999). The characteristic species of each community group were identified using species indicator analysis (Dufrene and Legendre 1993). Species indicator values are calculated based on the cover values of species within a group and the faithfulness of a species occurrence within a group (McCune and Mefford 1999). A Monte Carlo technique is used to test the significance of the indicator value of each species within a group. Multiresponse permutational procedures (MRPP) were used to test whether the species composition of the different communities was significantly different (Biondini *et al.* 1985). The test statistic describes the distance of the separation among groups (McCune and Mefford 1999). A value of 1.0 indicates perfect homogeneity of within-group membership and a value of 0 indicates that heterogeneity within groups is equal to that expected by chance alone. In community ecology, a value >0.3 is fairly high (McCune and Mefford 1999).

Detrended correspondence analysis (DCA), a reciprocal ordination technique that simultaneously ranks plots based on similarities of species composition and ranks species based on the plots in which they occur (McGarigal *et al.* 2000), was used to characterize the floristic nature of the species assemblages. DCA is an indirect ordination technique whereby environmental gradients are inferred from the plant species data based on the assumption that species covary in a systematic fashion because they are responding to the same underlying environmental variables. The Bray–Curtis index, a robust measure of ecological distances (Clarke 1993), was used to calculate dissimilarity in species composition among transects.

Jaccard's coefficient of similarity (J) was used to measure species overlap between transects: $J = A/(A + B + C)$, where A = the number of species found in both paired sites, B = species found in site 1 but not site 2 and C = species found in site 2 only (Chao *et al.* 2005). The J coefficient was calculated for all pairwise comparisons between sites (210 comparisons) using EstimateS software (Colwell 2005).

Results

A total of 21 sites and 109 transects consisting of 31 meadow, 40 shrub and 38 scree communities were sampled in seven strata (Fig. 1). We sampled as many sites as possible given time constraints imposed by the logistics of traveling to remote sites and sampling time in the field. The sites ranged from the eastern Hongshan mountain range in Shangri-la Conservation area, to the northern Baima Snow Mountains near the Tibetan border, the Meili Snow mountains on the western Tibet-Yunnan border and south to the Yunling Mountains and isolated alpine islands of the Laojunshan area (Fig. 1, Table 1). Sites are labeled according to their administrative village names.

Species richness patterns

A total of 369 species from 40 families and 116 genera were collected (Appendix 1), at least two of which were new species and several with newly recorded distributions. Species accumulation curves calculated for each site all began to level off by 60 m^2 of cumulative sample area (Fig. 2) indicating that our sampling effort was balanced and equal among sites. It is important to note that we were not sampling total species diversity. Our approach was to employ a standardized sampling approach to allow for the direct comparison of vegetation attributes among sites across the study area; thus, these numbers of species richness from this study are not directly comparable to other studies on alpine plant biodiversity.

Table 1 Summary characteristics of 21 sites sampled in the alpine of the Hengduan Mountains, Yunnan, China

Site name	Alpine site	Date sampled	Average elevation	Approximate location		Richness		
				UTM-north	UTM-east	Species	Genus	Family
BiRong	1	1 June 2004	4640	3139255	47588771	47	28	20
CiZhong	2	27 June 2004	4130	3097605	47479704	42	29	18
BaMei	3	6 July 2004	4457	3195112	47472896	40	32	23
BaMei	4	8 July 2004	4327	3194906	47471832	46	34	24
BaMei	5	12 July 2004	4698	3204756	47477560	51	36	20
BaMei	6	14 July 2004	4668	3203946	47478472	47	31	23
Adong	7	8 August 2004	4558	3170108	47495946	88	53	28
Adong	8	12 August 2004	4588	3157481	47492946	95	58	31
Meilishi	9	21 August 2004	4513	3162879	47464616	105	55	26
Meilishi	10	23 August 2004	4641	3161410	47465122	83	47	24
Yongzhi	11	1 September 2004	4238	3128855	47473889	33	25	18
Yongzhi	12	3 September 2004	4153	3111691	47472464	71	36	20
Baima Pass	13	7 September 2004	4503	3137119	47504462	104	64	31
Hongshan	14	11 September 2004	4446	3111932	47588729	80	45	28
Hongshan	15	12 September 2004	4431	3113574	47587376	74	44	27
Laojunshan	16	20 September 2004	4159	2971184	47562578	43	34	23
Laojunshan	17	21 September 2004	4188	2971847	47563179	19	15	12
Laojunshan	18	23 September 2004	4120	2945966	47573901	27	19	13
Laojunshan	19	24 September 2004	4220	2948515	47568841	39	32	21
Nagala	20	10 October 2004	4411	3143298	47569619	50	37	20
Nagala	21	13 October 2004	4443	3142551	47560939	64	45	23

Richness values reported are based on a sample area of 60 m^2.

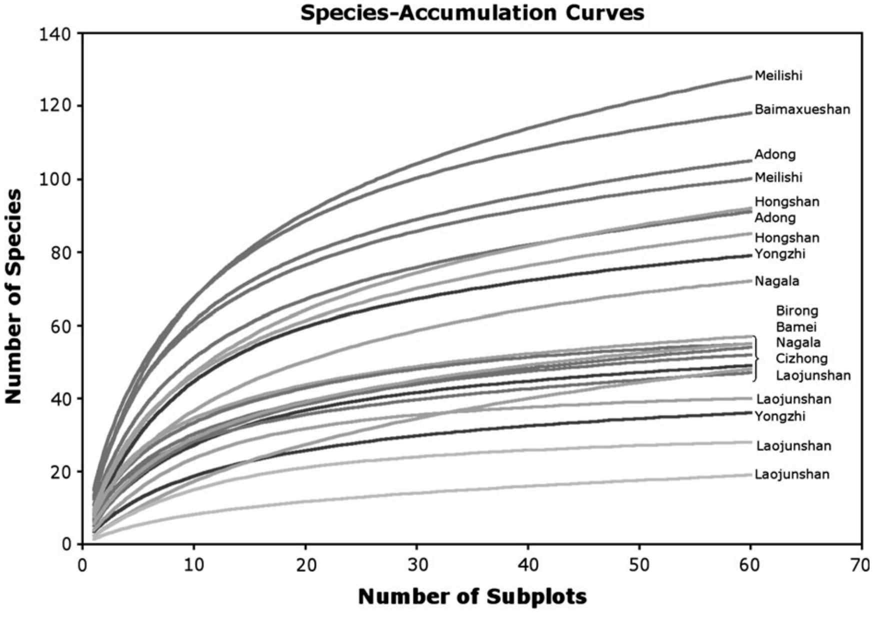

Figure 2 species accumulation curves for each of 21 alpine sites sampled in the Hengduan Mountains, Yunnan, China

Forb species richness varied greatly among sites, ranging from 19 to 105 species with an average of 59 species per site. Average species richness (number per 60 m^2) was significantly different among the seven sampling regions with richness greatest in the Baima Snow Mountains and lowest in the Laojunshan sites (Fig. 3). The majority of species encountered

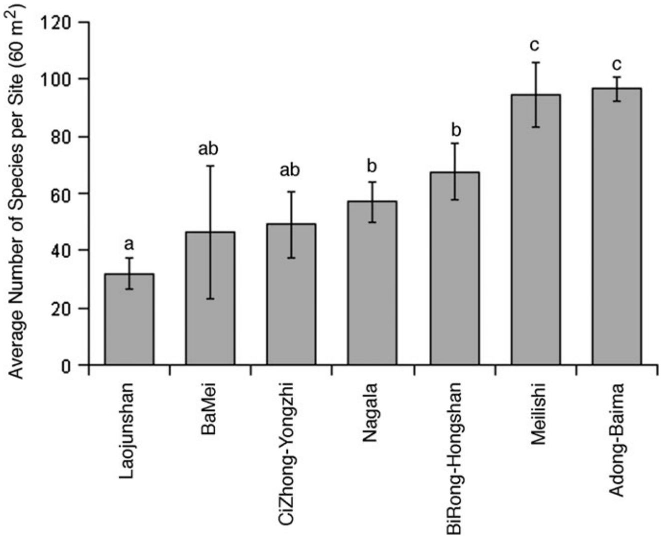

Figure 3 average species richness of alpine ecosystems in different regions of the Hengduan Mountains, Yunnan, China. See Figure 1 for location of named areas.

were endemic to the Hengduan Mountains (64%) and 15% were endemic just to the Hengduan Mountains of NWY. The greatest concentration of NWY endemics was found in the Baima and Meili Snow Mountains (26 species), which also had highest levels of species richness. Twenty-one species endemic to NWY were found in the northeastern mountain ranges, 13 species in the southwest mountain areas and 10 in Laojunshan.

There was little similarity in the species composition among sites and the amount of similarity generally decreased with distance among sites indicating high beta diversity across the region. Uncommon species, those occurring at only one site, comprised 38% of the total species and, those occurring at ⩽2 sites, accounted for 58% of the total species encountered. Alpine meadow species lists overlapped by 11 ± 0.9% among sites and ranged from 0 to 40 ($\mu = 6.7$) species between pairs of sites as calculated by Jaccard's coefficient of similarity. Shrub species overlapped by an average of 11 ± 0.6% (range 0–38%) ranging from 0 to 27 ($\mu = 7.4$) species, and species in the scree communities overlapped by an average of 9 ± 0.5% ranging from 0 to 17 species.

Predictive models of species richness

Several environmental factors and habitat characteristics were significant predictors of species richness in the different community types (Fig. 4). Variation in species richness among transects in the alpine meadows was related to the percent graminoid cover (positive—referred to as grass in the figure) and slope (positive), and accounted for ~55% of the variation (calculated as the residual deviance/null deviance) in species richness among sites. Percent grass cover (positive) and South.slope (positive, i.e., high sun index) were important

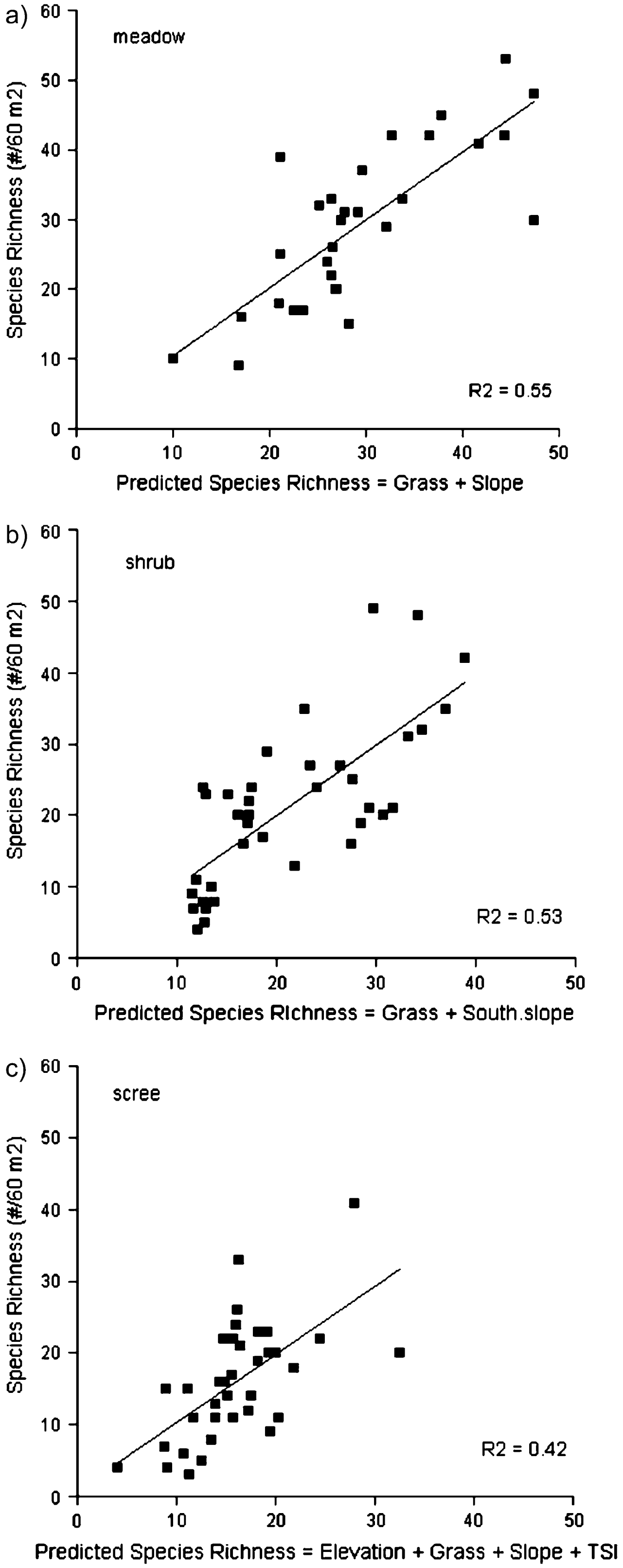

Figure 4 fitted values of species richness predicted by stepwise multiple regression using a Poisson distribution for three community types: a) meadow, b) shrub and c) scree. Significant explanatory variables fitted in each model are listed on the *x*-axis.

predictors of species richness in the shrub communities explaining 53% of the variation among transects (Fig. 4). Species richness of the scree communities was explained by elevation (positive), grass cover (positive), slope (positive) and TSI (positive, i.e., concave landform) with 42% of the total variation being explained by these predictors (Fig. 4).

Classification and ordination of vegetation

Alpine meadow communities

Cluster analysis of the 32 meadow vegetation transects identified six vegetation communities that differed in species composition and abundance (Fig. 5a, Table 2). The MRPP analysis indicated that there were strong differences between community groups identified by the cluster analysis ($A = 0.22$, $P < 0.001$).

The DCA clearly distinguished the four major meadow community groups identified by cluster analysis as indicated by the distinct separation of the communities along the first two DCA axes (Fig. 5b). The seven sampling strata (see Fig. 1) were superimposed on the DCA ordination plot and the communities identified by cluster analysis were circled. Transects in close geographic proximity grouped together indicating that they shared a more similar species composition suggesting that alpine meadows had distinct species assemblages in the different geographic regions (Fig. 6).

Significant habitat variables were overlaid as correlation vectors on the ordination plot; the length and direction of the vector represent the relative importance of the variable to the DCA axes. The first DCA axis was interpreted primarily as an elevation gradient (Table 5) as elevation explained 52% of the variation of this ordination axis. Axis 1 explained 46% of

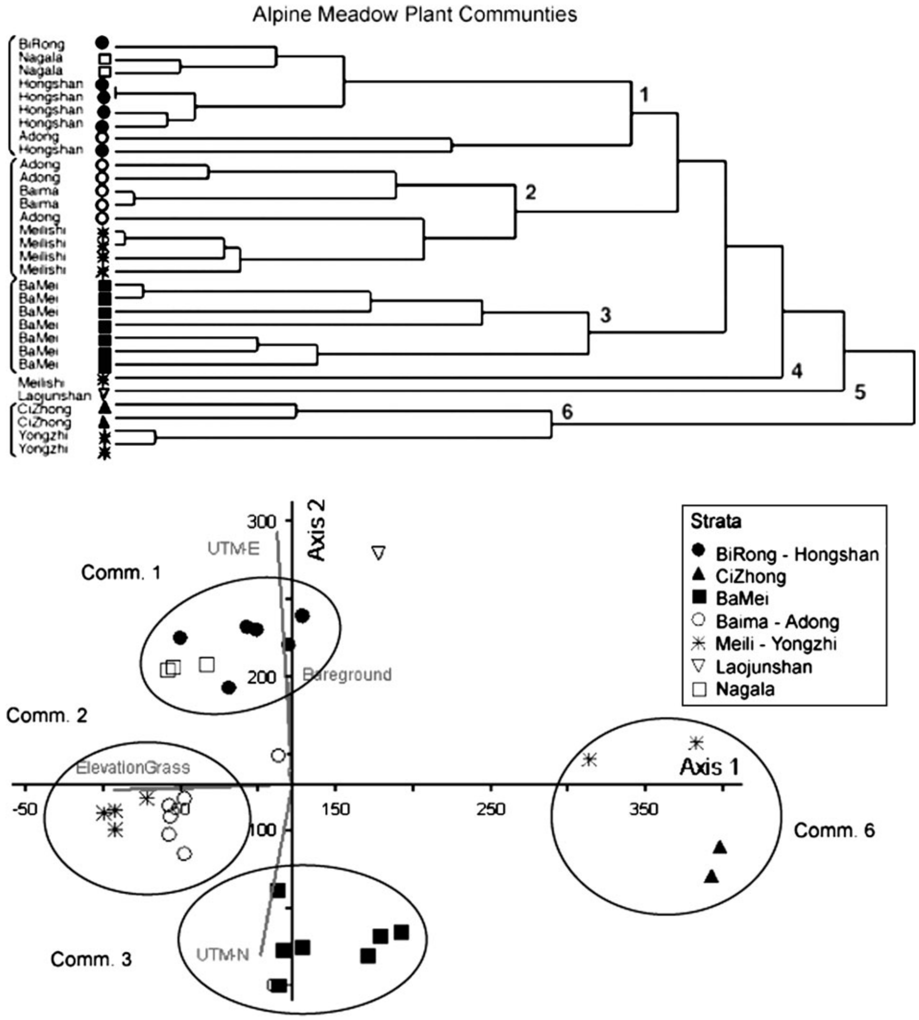

Figure 5 a) cluster analysis dendrogram of plant species composition of 31 vegetation transects from alpine meadows. b) ordination of 31 vegetation transects from alpine meadow communities in the Hengduan Mountains, Yunnan, China, using DCA. Strata that represent different mountain ranges used in the stratified random sampling design are superimposed on the ordination plot (see Fig. 1). The four major alpine meadow communities identified by cluster analysis are circled.

Table 2 Indicator species of four alpine meadow communities classified by cluster analysis

Family	Genus	Species	*P* value
Community 1			
Gentianaceae	*Gentiana*	*oreodoxa H. Smith*	0.001
Rosaceae	*Potentilla*	*stenophylla(Franch.)Diels*	0.001
Campanulaceae	*Cynanthus*	*zhongdianensis C. Y. Wu*	0.002
Rosaceae	*Potentilla*	*coriandrifolia*	0.004
Compositae	*Cremanthodium*	*delavayi (Franch.) Diels ex Levl.*	0.024
Gentianaceae	*Comastoma*	*pedunculatum (Royle ex D. Don) Holub*	0.024
Community 2			
Caryophyllaceae	*Arenaria*	*barbata Franch. Var. hirsutissima W. W. Smith*	0.001
Saxifragaceae	*Saxifraga*	*melanocentra*	0.001
Scrophulariaceae	*Pedicularis*	*roleyi Maxim.*	0.001
Crassulaceae	*Rhodiola*	*scabrida(Franch.)S.H.Fu*	0.001
Campanulaceae	*Cynanthus*	*macrocalyx Franch.*	0.001
Umbelliferae	*Pleurospermum*	*hookeri C. B. Clarke var. thomsonii C. B. Clarke*	0.001
Community 3			
Papilionaceae	*Thermopsis*	*smithiana Piter-Stib.*	0.001
Umbelliferae	*Physospermopsis*	*shaniana C. Y. Wu et Pu*	0.001
Gentianaceae	*Gentiana*	*caelestis (Marq.) H. Smith*	0.004
Scrophulariaceae	*Pedicularis*	*elwesii Hook. f.*	0.006
Primulaceae	*Androsace*	*tapete Maxim.*	0.007
Community 4			
Rosaceae	*Potentilla*	*penducularis D. Don var. penducularis*	0.001
Polygonaceae	*Polygonum*	*calostachyum Diels*	0.001
Primulaceae	*Primula*	*calliantha Franch. subsp. bryophila (Balf. f & Farrer.) W.W. Smith & Forrest*	0.001
Saxifragaceae	*Bergenia*	*purpurascens*	0.002
Primulaceae	*Primula*	*silaensis Petitm.*	0.002

The five most important species with a significance value of $P \leqslant 0.1$ were reported for each group in their order of significance. More than five species were reported if significance values were the same among species.

the total variance in the species matrix. Low axis scores were associated with the high elevation, western sites from the Baima Snow Mountains and northern Meili Snow Mountains. These sites also had a high percentage of graminoid cover in the meadows. The second axis was strongly related to geographic location. The Universal Transverse Mercator (UTM) coordinates (east and north) explained 83% of the variation in this ordination axis but accounted for only 15% of the species locations in the ordination. The most northern sites sampled at BaMei were arranged at the lower end of this axis and the most eastern sites of the Hongshan range were arranged on the upper end of Axis 2. The third axis did not have much explanatory power (Table 5).

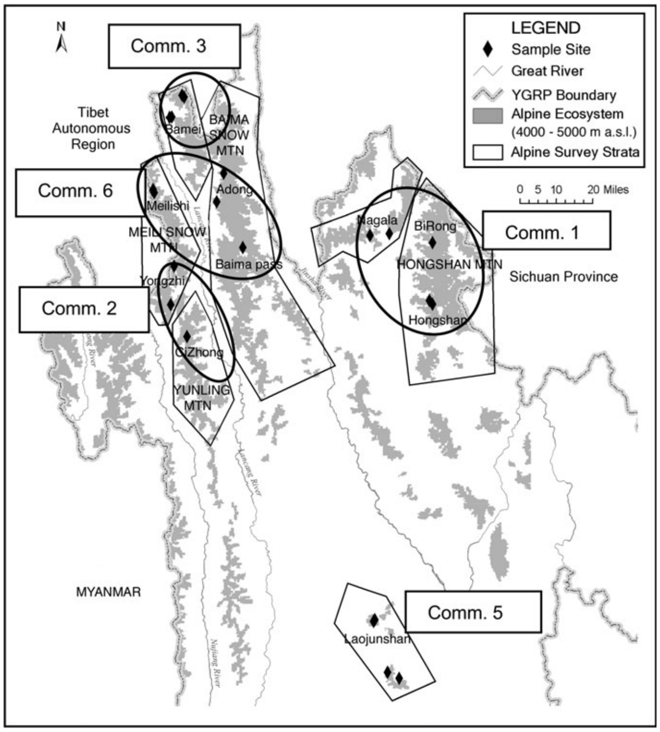

Figure 6 geographic location of the five major alpine meadow communities identified by cluster analysis

Alpine shrub communities

The shrub communities were combined into eight species assemblages by cluster analysis (Fig. 7a). Separation among groups as tested by MRPP was high ($A = 0.31$, $P < 0.001$). The different communities were largely defined by the dominant shrub species (Table 3). South-facing slopes were dominated by two species of *Sabina* (Cupressaceae) (Communities 1 and 3) whereas north-facing slopes were dominated by several different species of *Rhododendron* (Table 3). The eight shrub communities identified by cluster analysis were not as strongly separated in the DCA plot as compared to the meadow communities (Fig. 7b). Most of the shrub communities (Communities 1, 2, 3, 4 and 7) were widely distributed as indicated by the range of sites that comprised each group (Fig. 7b). In contrast, shrub communities 5, 6 and 8 had strong geographic affinities. Community 6 consisted of the most northern BaMei sites, Community 8 was defined by the most southern sites of Laojunshan and Community 5 in the southern Meili Mountains and northern Yunling Mountains.

The first axis of the DCA ordination of the shrub vegetation was interpreted as a complex environmental gradient related to slope aspect (Table 5). The axis was significantly related to South.slope (sun index), UTM-north, Species Richness and Graminoid cover which accounted for 26% of the variance in the species composition (Table 5). Communities at the lower end of Axis 1 tended be high elevation sites with south to southwest aspects. The two Sabina-dominated shrub

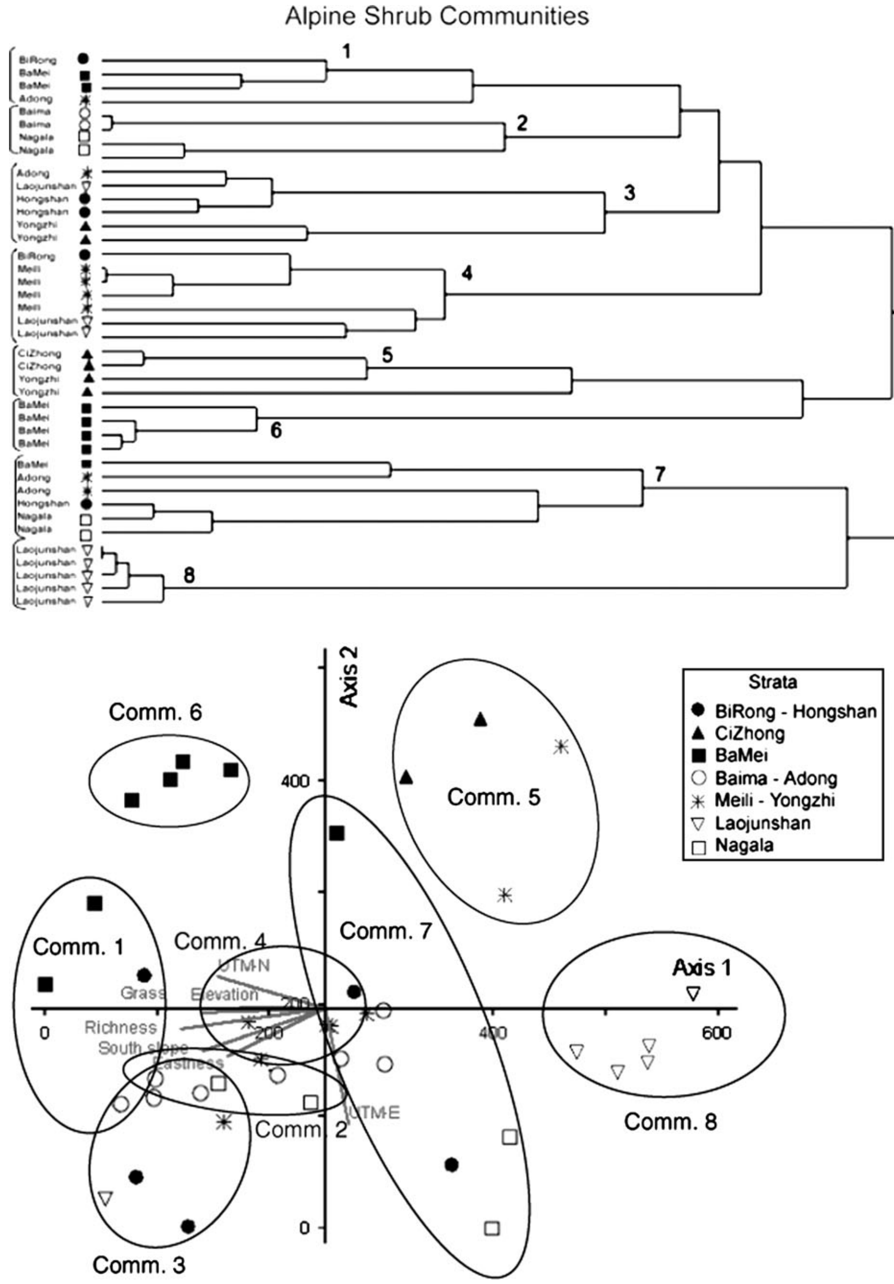

Figure 7 a) cluster analysis dendrogram of plant species composition of 40 vegetation transects from alpine shrub communities. b) ordination of 40 vegetation transects from alpine shrub communities in the Hengduan Mountains, Yunnan, China, using DCA. Strata that represent different mountain ranges used in the stratified random sampling design are superimposed on the ordination plot (see Fig. 1). The eight alpine shrub communities identified by cluster analysis are circled.

communities were associated with low scores of this axis as was Community 2, a *Rhododendron complexum–Rhododendron orthocladum* shrub community. These sites also had higher species richness and greater graminoid cover than the Laojunshan sites that were arranged at the upper end of Axis 1. Axis 2 was most strongly related to the east UTM coordinates (34%) and accounted for 17% of the variance in species composition. The plant community groups were not strongly arranged along this axis. Axis 3 was interpreted as an elevational gradient and accounted for 9% of the variance in the species structure (Table 5).

Alpine scree communities

The scree communities were divided into six species assemblages (Fig. 8a). Community 2 was the largest group and was comprised of 17 transects from sites across three mountain ranges, the Meili Snow Mountains, Baima Snow Mountains and the Hongshan range, and characterized by 11 species.

Table 3 Indicator species of eight alpine shrub communities classified by cluster analysis

Family	Genus	Species	*P* value
Community 1			
Cupressaceae	*Sabina*	*squamata Buchanan-Hamilton ex D. Don*	0.001
Primulaceae	*Androsace*	*tapete Maxim.*	0.030
Compositae	*Aster*	*diplostephioides (DC.) C. B. Clarke*	0.030
Papaveraceae	*Meconopsis*	*integrifolia (Maxim.) Franch. Var. integrifolia*	0.053
Onagraceae	*Epilobium*	*sp.*	0.069
Community 2			
Compositae	*Pyrethrum*	*tutsienense (Bur. Et Franch.) Ling et Shih*	0.001
Umbelliferae	*Vicatia*	*coniifolia (Wall) DC.*	0.012
Rosaceae	*Potentilla*	*coriandrifolia*	0.012
Liliaceae	*Aletris*	*pauciflora (Klotz.) Franch.*	0.018
Gentianaceae	*Lomatogonium*	*longifolium H. Smith*	0.025
Ericaceae	*Rhododendron*	*complexum Balf. f. et W. W. Smith*	0.025
Campanulaceae	*Codonopsis*	*bulleyana Forrest ex Diels*	0.025
Community 3			
Cupressaceae	*Sabina*	*wallichiana J.D.Hooker et Thomosonex E.Brandis*	0.001
Caprifoliaceae	*Lonicera*	*hispida Pall.*	0.008
Saxifragaceae	*Saxifraga*	*hispidula*	0.008
Rosaceae	*Potentilla*	*glabra Lodd.Bot Cab.*	0.015
Primulaceae	*Primula*	*bella Franch.*	0.040
Community 4			
Ericaceae	*Rhododendron*	*nivale Hook.f.ssp. Boreale Philipson et M.N. Philipson*	0.001
Umbelliferae	*Chamaesium*	*viridiflorum (Franch.) Wolff ex Shan*	0.003
Furmariaceae	*Corydalis*	*pseudo-adoxa C. Y. Wu et H. Chuang*	0.025
Saxifragaceae	*Saxifraga*	*elatinoides*	0.058
Community 5			
Ericaceae	*Cassiope*	*sp.*	0.001
Ericaceae	*Rhododendron*	*sanguineum Franch.*	0.001
Polygonaceae	*Polygonum*	*calostachyum Diels*	0.003
Ranunculaceae	*Oxygraphis*	*delavayi Franch.*	0.007
Gentianaceae	*Gentiana*	*phyllocalyx C.B.Clarke*	0.008
Community 6			
Ericaceae	*Rhododendron*	*sp.*	0.001
Papilionaceae	*Thermopsis*	*smithiana Piter-Stib.*	0.001
Polygonaceae	*Polygonum*	*macrophyllum D. Don*	0.001
Umbelliferae	*Physospermopsis*	*shaniana C. Y. Wu et Pu*	0.002
Ranunculaceae	*Anenome*	*obtusiloba D. Don ssp. ovalifolia Bruhl*	0.004
Community 7			
Ericaceae	*Rhododendron*	*tapetiforme Balf. f. et K.Ward*	0.021
Ericaceae	*Rhododendron*	*aganniphum Balf. f. et Ward*	0.026
Ericaceae	*Cassiope*	*selaginoides Hook. f. et Thoms.*	0.047
Community 8			
Ericaceae	*Rhododendron*	*alutacenum Balf. f. et W. W. Smith*	0.001
Umbelliferae	*Acronema*	*wolffianum Fedde ex Wolff*	0.006
Saxifragaceae	*Bergenia*	*purpurascens*	0.009
Ericaceae	*Cassiope*	*selaginoides Hook. f. et Thoms.*	0.047

The five most important species with a significance value of $P \leqslant 0.1$ were reported for each group in their order of significance. More than five species were reported if significance values were the same among species.

These two plant assemblages can be considered typical scree communities. Scree community group 3 was represented by species more typical of meadow communities than scree plants (Table 4). These sites were in the lower elevation mountains of the Yunling and southern Meili Snow ranges. Community Group 4 consisted of the Laojunshan sites. The scree in these low elevation mountains was dominated by large rocks and boulders with very little substrate on which plants could become established. These Laojunshan sites contained very few species, but *Rhodiola nobilis* occurred on all transects.

The DCA ordination of the scree vegetation did not have much explanatory power. The scree communities were separated along the two axes, but their relationship to landscape variables could not be described based on the environmental matrix we measured (Fig. 8b). The three DCA axes combined explained only 24% of the variance in the species composition indicating that other unmeasured environmental variables were important in structuring the ordination. The axes were difficult to interpret ecologically as all three axes appeared to be related to geographical position (Table 5).

Discussion

The alpine flora of NWY is highly heterogeneous across the complex mountain landscape. Although we conducted a coarse-scale analysis of forb species distribution patterns, the 21 sites sampled were distributed across a broad geographic range and strong patterns emerged. One of the most striking findings of this study was the high beta diversity across the region. Most species were locally rare and patchily distributed; over half the species occurred at only one or two sites. There was little overlap in the species composition among sites and the amount of overlap generally decreased with distance between sites indicating that many alpine species are not widespread and/or that widespread species have very patchy and

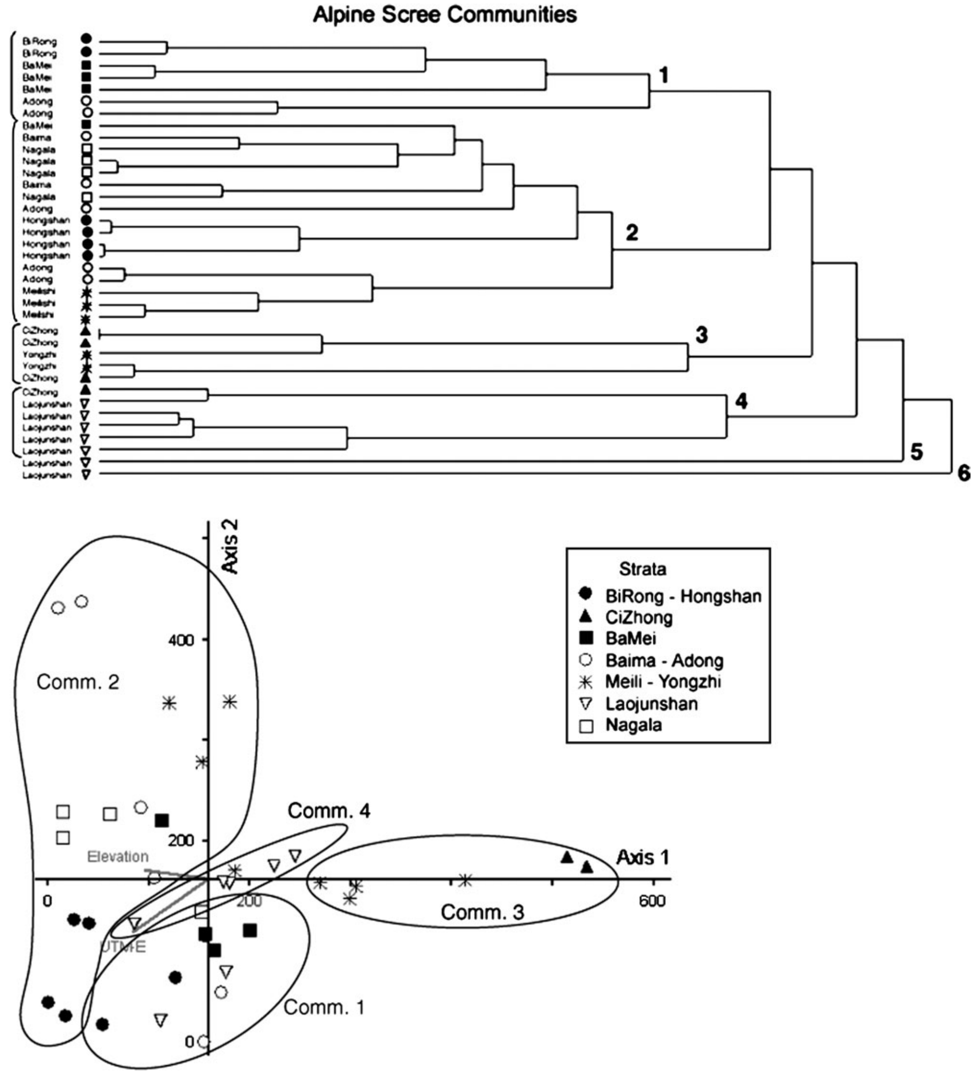

Figure 8 a) cluster analysis dendrogram of plant species composition of 37 vegetation transects from alpine scree communities. b) ordination of 37 vegetation transects from alpine scree communities in the Hengduan Mountains, Yunnan, China, using DCA. Strata that represent different mountain ranges used in the stratified random sampling design are superimposed on the ordination plot (see Fig. 1). The four major alpine scree plant communities identified by cluster analysis are circled.

isolated populations (Ge *et. al.* 2005). In particular, the alpine meadows had distinct species assemblages that varied by geographic region, evidenced by the strong separation of communities along the DCA axes in the ordination. These results suggest the presence of distinct phytogeographic zones with unique alpine meadow communities in the different geographic regions of NWY.

The indirect gradient analysis revealed that elevation and geographic location were the dominant gradients underlying regional differences in the species composition among sites. Undoubtedly, this pattern reflects environmental differences among locations, such as differences in climate and soils, although we did not measure these attributes. In addition, the role of local variation in topographic factors, such as slope, aspect and landform, in regulating species distribution patterns at the site level was evident from the regression analysis. These results are consistent with other studies that have demonstrated the importance of climate, topography and soils in regulating vegetation patterns across alpine landscapes (e.g. Chapin and Körner 1995; Körner 2003; Walker *et al.* 2001). Although the regression models and ordinations provide some insights into factors that influence species composition and diversity patterns across the alpine in NWY, these are based on a limited suite of measurements that are correlative in nature. Much more detailed studies are needed that examine the underlying mechanisms that control species distribution patterns.

Given the island-like nature of mountains, many authors have examined the variation in richness of alpine floras within

Table 4 Indicator species of four alpine scree communities classified by cluster analysis

Family	Genus	Species	*P* value
Community 1			
Caryophyllaceae	*Arenaria*	*polytrichoides Edgew. Ex Edgew. Et Hook. f.*	0.001
Compositae	*Anaphalis*	*xylorhiza Sch.-Bip. Ex Hook. f.*	0.006
Crassulaceae	*Rhodiola*	*scabrida(Franch.) S.H.Fu*	0.006
Ranunculaceae	*Anenome*	*obtusiloba D. Don ssp. ovalifolia Bruhl*	0.007
Saxifragaceae	*Saxifraga*	*pulchra Engl. et Irmsch.*	0.014
Community 2			
Caryophyllaceae	*Arenaria*	*barbata Franch. Var. hirsutissima W. W. Smith*	0.001
Compositae	*Stebbinsia*	*umbrella (Franch.) Lipsch.*	0.001
Labiatae	*Eriophyton*	*wallichii Buch ex Wall.*	0.005
Compositae	*Syncalathium*	*souliei (Franch.) Ling*	0.016
Papilionaceae	*Astragalus*	*acualis Baker*	0.027
Community 3			
Polygonaceae	*Polygonum*	*calostachyum Diels*	0.003
Saxifragaceae	*Saxifraga*	*ciliatopetala (Engl. Et Irmsch.) J. T. Pan*	0.003
Polygonaceae	*Polygonum*	*macrophyllum D. Don*	0.005
Cruciferae	*Loxostemon*	*pulchellus Hook. f. et Thoms.*	0.005
Rosaceae	*Sibbaldia*	*cuneata Hornem. Ex Ktze.*	0.015
Ranunculaceae	*Oxygraphis*	*delavayi Franch.*	0.015
Crassulaceae	*Sedum*	*przewalsikii Maxim.*	0.015
Gentianaceae	*Gentiana*	*filistyla Balf.f. et Forrest ex Marq.*	0.015
Geranianaceae	*Geranium*	*farreri Stapf*	0.015
Community 4			
Crassulaceae	*Rhodiola*	*nobilis (Franch.)S.H.Fu*	0.001
Rosaceae	*Potentilla*	*glabra Lodd.Bot Cab.*	0.016

The five most important species with a significance value of $P \leqslant 0.1$ were reported for each group in their order of significance. More than five species were reported if significance values were the same among species.

the context of island biogeography theory. It has been demonstrated that the richness of alpine floras varies with the size of an individual alpine ecosystem and distance to sources of new species, i.e., nearest alpine area (Hadley 1987; Riebesell 1982). In NWY, the more northern Meili and Baima Snow Mountains had the highest levels of species richness. These are high elevation ranges with extensive, contiguous alpine areas and broad expansive meadows. In contrast, the isolated mountain peaks of Laojunshan in the more southern part of NWY that have steep, sharp ridges with limited alpine meadows had the lowest overall plant diversity. These observations are consistent with the equilibrium theory of island biogeography.

We expected that that the mountaintops of ranges that have been separated by the deep river valleys through geologic time might function as habitat islands and harbor unique vegetation communities. However, the alpine vegetation in the Baima Snow Mountains and the northern Meili Snow Mountains, which are separated by the deep river canyon of the Lancang (Mekong) River, grouped together in both the cluster analysis and ordination, indicating that the deep valleys have not acted as strong geographic barriers to species migrations (Fig. 6). Moreover, the species composition of the alpine vegetation in the southern Meili Snow Mountain range was more similar to the vegetation in the Yunling Mountains than to plant communities in the northern Meili Snow Mountains (Fig. 6). These sites receive greater amounts of rainfall and have longer snow cover than the more northern sites that are in the rain shadow of the Meili mountains. Hence, the highly variable climatic conditions across these mountains no doubt have a strong influence on vegetation patterns across the region.

Grazing was prevalent throughout the alpine and clearly had an impact on the vegetation as evidenced by the dominance of low-statured species in the meadows. An intriguing relationship was the high correlation between forb species richness and graminoid cover that was found in all three alpine community types. This pattern is difficult to interpret as we did not identify the different graminoid species in our plots; however, this relationship most likely is related to grazing patterns and deserves further attention.

Overall, the plant species data did not suggest a problem in the form of dominance by a few nuisance species that would be indicative of high grazing pressure with the exception of the eastern sites that had meadows dominated by two *Potentilla* species. Moreover, the amount of bareground in a plot typically was <2% of the area; large areas of exposed soil and erosion would indicate over grazing (Driscoll et al. 1999). Many of the attractive flowering plants that characterize the high alpine meadows persist in large numbers because grazing suppresses their opportunistic competitors, including many of the mat-forming species and rosettes that grow close to the ground to evade grazing (Körner 2000; Meihe 1997). Our plant data were consistent with views of local herders who indicated that there has been little degradation in the pasturelands above tree line over the years (Buntaine *et al.* 2007). Although there is a common perception that the alpine in NWY is being degraded, our data suggest that grazing is not a threat to the alpine biodiversity at a regional scale. Localized areas may be experiencing high pressure (Wilkes 2006), but problems of over-concentrated grazing are more common than over grazing (Xu and Wilkes 2003). Based on personal field observations and discussions with herders, the condition of the subalpine (below treeline) appears to be an issue of greater concern (Wilkes 2006).

It was clear that many of the sites we sampled had been disturbed and were in various stages of succession. For example,

Table 5 **Pearson correlation coefficients between species and landscape parameters of DCA axis scores based on ordinations of three plant community types in 21 alpine ecosystems in the Hengduan Mountains, Yunnan, China**

	Meadow communities			Shrub communities			Scree communities		
Variable	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Richness	−0.350	−0.048	0.025	**−0.655**	−0.249	0.087	−0.119	−0.049	0.124
Elevation	**−0.718**	−0.121	−0.023	**−0.497**	0.051	**−0.492**	**−0.461**	0.170	**0.391**
UTM-N	−0.300	**−0.700**	0.128	**−0.563**	0.305	−0.464	−0.137	0.211	**0.363**
UTM-E	−0.211	**0.851**	−0.201	0.265	**−0.584**	−0.076	**−0.499**	**−0.420**	−0.116
Slope	0.423	0.154	−0.014	0.317	−0.216	**0.429**	0.223	0.296	−0.326
TSI	−0.027	−0.085	**0.330**	0.045	−0.039	**−0.405**	−0.134	0.064	−0.081
South.slope	−0.246	0.326	−0.081	**−0.603**	−0.358	0.133	−0.168	0.028	−0.013
East.slope	−0.046	0.328	−0.145	0.210	0.188	−0.167	−0.257	−0.075	−0.121
Bareground	−0.107	**0.541**	−0.327	0.199	0.132	−0.162	—	—	—
Eastness	−0.126	0.327	−0.098	**−0.537**	−0.376	0.118	−0.174	0.016	−0.139
Southness	−0.237	0.404	−0.001	−0.392	−0.029	−0.172	−0.185	0.066	0.033
Rock	−0.176	0.244	−0.088	−0.114	−0.259	**0.499**	−0.357	**0.381**	−0.323
Graminoid	**−0.660**	−0.123	−0.149	**−0.606**	−0.102	0.207	0.251	−0.224	0.153
Correlation with DCA axis (r^2)	0.46	0.15	0.04	0.26	0.17	0.09	0.10	0.07	0.07

some of the meadow communities contained species more typical of shrub communities and some of the dominant plants in the shrub communities were species more typical of alpine meadows. Prescribed fire is a traditional land management tool used by herders to keep pastures open and promote the growth of palatable species (Buntaine *et al.* 2007; Meihe 1997). However, the use of fire in the alpine has been restricted due to regulatory policies that were implemented to protect forests but universally applied to all ecosystems (Moseley 2006; Wilkes 2006; Yi *et al.* 2007). The result has been the encroachment of shrubs onto traditional summer pasturelands and the loss of grazing areas. An unanticipated consequence of these regulations could be the concentration of grazing animals in fewer and smaller areas.

The history of human use in the alpine dates back thousands of years. Grazing has been a part of the disturbance regime of the alpine for >2000 years (Foggin and Smith 1996; Miller 1999) and fire for at least the last 100 years (Baker and Moseley 2007) and most likely much longer. Traditional resource management systems clearly have not had a negative impact on the landscape but rather have created the vegetation mosaic that exists today. However, rapid economic development, increased tourism and cultural transformations occurring in NWY (Xu and Wilkes 2003; Xu *et al.* 1999) potentially threaten to change this balance. In the face of such change, controversial issues such as grazing and the use of fire need to be approached with clarity of goals, scientific objectivity and rigor before sweeping policy reforms are implemented. Maintaining the long-term health and integrity of alpine ecosystems in NWY is crucial for conserving both the rich biological diversity and the rich cultural heritage of the region. Proactive measures taken now will help to preserve the biota and cultural life of these mountains and avert the many problems other parts of the Himalayan highlands are now experiencing (Byers 2005; Foggin and Smith 1996; Miller 2002).

Conclusions

We present the first quantitative analysis of vegetation patterns across the high alpine regions of the Hengduan Mountains of NWY. This study is preliminary in nature given that we were able to sample during one field season only; a much more extensive sampling effort is necessary in order to better quantify spatial and temporal vegetation patterns across these diverse mountains. However, the data has demonstrated that the vegetation of the alpine is very heterogeneous across the complex landscape of the Hengduan Mountains of NWY. This poses a challenge to conservation planners as it requires the protection of large numbers of species over a large geographical area. The majority of species were locally rare and patchily distributed. Conservation strategies often focus on areas of high biodiversity, but, because there were large regional differences in the species composition, even the lower diversity sites, such as Laojunshan, harbor unique species that need protection. Thus, regional conservation strategies that take into account the large geographic differences in the flora are necessary in order to maximize protection of alpine biodiversity. Our results do not support the common assumption that the alpine is being degraded. Improved scientific understanding of the impacts of grazing and fire on alpine biodiversity is needed to guide effective conservation policies.

Funding

The Nature Conservancy—China Program.

Appendix 1
Species list of alpine plants collected in the Hengduan Mountains, NWY, China

Family	Genus	Species	Distribution
Amaryllidaceae	*Allium*	*beesianum W.W. Smith*	DC
		forrestii Diels	DCZ-H
		prattii C.H. Wight apud Forb.et Hemsl	Sino-Himal.
		sikkimense Baker	Sino-Himal.
		wallichii Knuth var. wallichii	Sino-Himal.
Araceae	*Arisaema*	*parvum L.*	DCZ-H
Berberidaceae	*Berberis*	*dawoensis K. Meyer*	DCZ-H
		dictyophylla Franch.	SW China
		tsarongensis Stapf	DZ-H
Bignoniaceae	*Incarvilea*	*younghusbandii Sprague*	DZQ (new to Yunnan)
Boraginaceae	*Chionocharis*	*hookeri (Clarke) Johnst.*	DCZ-H
	Eritrichium	*brachylubum (Diels) Lian et J. Q. Wang*	DCZ-H
	Microula	*oblongifolia Hand.-Mazz. Var. glabrescens W. T. Wang*	D-H
		spathulata W. T. Wang	D-H
		younghusbandii Duthie	DCZQ-H
Campanulaceae	*Campanula*	*colorata Wall.*	DCZ-H
	Codonopsis	*bulleyana Forrest ex Diels*	DCZ-H
	Cynanthus	*fasciculatus Marq.*	DCZ-H
		formosus Diels	DC-H
		incanus Hook.f. et Thoms.	H-Himal.
		macrocalyx Franch.	H
		petiolatus Franch.	DC-H
		zhongdianensis C. Y. Wu	D-H
Caprifoliaceae	*Lonicera*	*cyanocarpa Franch.*	DCZ-H
		hispida Pall.	DCZ-H
		myrtillus Hook. f. et Thoms.	DCZ-H
Caryophyllaceae	*Arenaria*	*barbata Franch. Var. hirsutissima W. W. Smith*	D-H
		euodonta W. W. Smith	D-H
		inornata W. W. Smith	D-H
		kansuensis Maxim.	H
		longistyla Franch.	DC-H
		membranisepala C. Y. Wu	D-H
		nivalomontana C. Y. Wu ex L. H. Zhou	D
		polytrichoides Edgew. Ex Edgew. Et Hook. f.	H-Himal.
		smithiana Mattf.	DZ-H
		sp.	
		xerophila W. W. Smith	DC-H
	Silene	*nigrescens (Edgew.) Maj*	DZM-H
	Stellaria	*decumbens Edgew.*	H-Himal.
		uliginosa Murr.	N temp.
Chenopodiaceae			
Compositae	*Ajania*	*khartensis (Dunn) Shih*	Himal. to N As.
	Anaphalis	*chlamydophylla Diels*	D-H
		flavescens Hand.-Mazz.	
		nepalensis Spreng.) Hand.-Mazz. Var. mponocephala (DC) Hand.-Mazz.	
		pannosa Hand.-Mazz.	D
		viridis Cumm.	DCZ-H
		xylorhiza Sch.-Bip. Ex Hook. f.	H-Himal.
	Artemisia	*sp.*	
	Aster	*asteroides (DC.) O. Ktze.*	H-Himal.
		bathangensis Bur. Et Franch.	DCZ-H
		diplostephioides (DC.) C. B. Clarke	DCZ-H
		handelii Onno	DC-H
		himalaicus C. B. Clarke	H-Himal.
		souliei Franch.	H-E Himal.
	Cremanthodium	*campanulatum (Franch.) Diels*	DCZM-H
		delavayi (Franch.) Diels ex Levl.	DM-H
		helianthus (Franch.) W. W. Smith	DC-H
		nanum (Decne) W. W. Smith	Sino-Himal.
		pulchrum R. Good	DM-H
		rhodocephalum Diels	DCZ-H
	Leontopodium	*celocephalum (Franch.) Beauv.*	H
		souliei Beauv.	H
	Ligularia	*melanocephala (Franch.) Hand.-Mazz.*	DC-H
		subspicata (Bur. Et Franch.) Hand.-Mazz.	DC-H
	Pyrethrum	*tutsienense (Bur. Et Franch.) Ling et Shih*	H
	Saussurea	*cochlearifolia Y. L. Chen et S. Y. Liang*	DZ
		graminea Dunn	DCZ
		hieracioides Hook. f.	Sino-Himal.
		hirsuta (Anth.) Hand.-Mazz.	D-H
		integrifolia Hand.-Mazz.	DC-H
		katochaeta Maxim.	W C China
		leontodontoides (DC.) Sch.-Bip.	Sino-Himal.
		ligulata Franch.	DC-H
		ochrochlaena Hand.-Mazz.	DZ-H
		semilyrata Bur. Et Franch.	DCZ-H
		simpsoniana (Field. et Gardn.) Lipsch.	Himal. to C As.

Appendix 1
Continued

Family	Genus	Species	Distribution
		spathulifolia Franch.	DC-H
		umbrella	
		velutina W. W. Smith	DCZ
		wellbyi Hemsl. (new to Yunnan)	NW China
	Soroseris	*erysimoides (Hand.-Mazz.) shih*	Sino-Himal.
		gillii (S. Moore) Stebb.	W C China
		hirsula (Anth.) Shih	W C China
	Stebbinsia	*umbrella (Franch.) Lipsch.*	DCZ-H
	Syncalathium	*souliei ?Franch.) Ling*	DCZ-H
	Taxacum	*forrestii V. Soest*	H-Himal.
		sikkimensis Hand.-Mazz.	Sino-Himal.
		suberiopodum V. Soest	D-H
Crassulaceae	*Rhodiola*	*atuntsuensis(Praeg.)S.H.Fu*	D-H
		bupleuroides Wall.	H-Himal.
		crenulata (Hook. f. et Thoms.)H.Ohba	H-Himal.
		discolor(Franch.)S.H.FU	H-Himal.
		fastigacata (Hook. f. et Thoms.)S.H.Fu	Sino-Himal.
		multibracteata H. Chuang	D-H
		nobilis (Franch.)S.H.Fu	D-H
		scabrida(Franch.)S.H.Fu	DC-H
		sp.	
		wallichiana var.cholaensis (Praeg.)S.H.Fu	H-Himal.
	Sedum	*luchuanicum K. T. Fu*	D-H
		oreades(Decene.) Hamet	H-Himal.
		przewalsikii Maxim.	WCChina
		raymondii Frod.	DC-H
Cruciferae	*Draba*	*alpina L.Sp.Pl.*	NAs.-H-Himal.
		altaica(C.A.Mey.)Bunge var.modesta(W. W. Smith)O.E.Schulz	DCZX
		ellipsoides Hook. f. et Thoms.	Sino-Himal.
		fladnizensis Wulfen.	NAs.
		lichangensis W. W. Smith	WCChina
		oreades Schrenk var.oreades	WCChina-Himal.
		oreodoxa W. W. Smith	D-H
	Eutrema	*ooliquum K.G.Kuan et Z.X.An*	Z(new distribution in D)
	Loxostemon	*delavayi Franch.*	DCZ
		loxostemonoides (O.E.Schulz)Y.C. Lan et T.Y.Che	Himal.
		pulchellus Hook. f. et Thoms.	H-Himal.

Appendix 1
Continued

Family	Genus	Species	Distribution
	Solms-Laubachia	*latifolia(O.E.Schulz) Y.C.Lan et T.Y.Cheo*	C(new distributiuoon iin D)
		linearifolia(W. W. Smith)O.E.Schulz	D
		pulcherrima Muschl. f.pulcherrima	DC
	Staintoniella	*verticillata (Jeffrey et W. W. Smith) Hara*	Sino-Himal.
Cupressaceae	*Sabina*	*squamata Buchanan-Hamilton ex D. Don*	WCChina to SChina-H-Himal.
		wallichiana J.D.Hooker et Thomosonex E.Brandis	DZ-Himal.
Diapensiaceae	*Diapensia*	*himalaica Hook.f. et Thoms.*	DZ
		purpurea Diels	DC
Dipsacaceae	*Morina*	*nepalensis*	
		alba	
Ericaceae	*Cassiope*	*selaginoides Hook. f. et Thoms.*	DCZ-Himal.
	Diplarche	*mulitflora Hook. f. et Thoms*	E Himal.
		pauciflora Hook. f. et Thoms	E Himal.
	Gaultheria	*prostrataW. W. Smith*	D-H
		sinensisAnth.var.sinensis	E Himal.
	Rhododendron	*aganniphum Balf. f. et Ward*	DCZ
		beesianum Diels	DCZM-H
		campylogynum Franch.	DZM-H
		complexum Balf. f. et W. W. Smith	DC-H
		forrestii Balf.f.ex Diels	DZM-H
		heliolepsis Franch.	DZM-H
		nivale Hook.f.ssp. Boreale Philipson et M.N.Philipson	H
		orthocladum Balf. f. et.Forrest	DCQ
		phaeochrysum Balf. f. et W. W. Smith	DCZ
		primuliflorum Bue.et Franch.	DCZ
		rupicola W. W. Smith var. chryseum	DM-H
		saluenense Franch.var. prostratum	D
		sanguineum Franch.	DZ
		sp.	
		tapetiforme Balf. f. et K.Ward	DZ-H
		traillianum Forrest et W. W. Smith	DCZ
		yungningense Balf.f. ex.Hutch.	

Appendix 1
Continued

Family	Genus	Species	Distribution
D-H			
Euphorbiaceae	*Euphorbia*	*stracheyi Boiss*	W C China
Fagaceae	*Quercus*	*sp.*	
Furmariaceae	*Corydalis*	*andrieni Prain*	DCZ-H
		atuntsuensis W. W. Smith	DCZQ-H
		benecincta W. W. Smith	DZ-H
		delavayi Franch.	DC-H
		densispica C. Y. Wu et H. Chuang	DCZ-H
		hemidicentra Hand.-Mazz.	D-H
		polyphylla Hand.-Mazz.	DZ-H
		porphyrantha C. Y. Wu et H Chuang	D-H
		pseudo-adoxa C. Y. Wu et H. Chuang	DZ-H
Gentianaceae	*Comastoma*	*cyananthiflorum (Franch. ex Hemsl.) Holub*	WCChina
		falcatum (Turcz. Ex Kar. et Kir) Toyokuni	Himal. to N As.
		pedunculatum (Royle ex D. Don) Holub	Sino-Himal.
		Ruthii (sp. Nov.)	D-H
		stellariifolium(Franch.ex Hemsl.) Holub	E Himal.
	Gentiana	*ampla H. Smith*	D-H
		arethusae Burk.var. delicatula Marq.	W C China
		atuntsiensis W. W. Smith	DCZ-H
		caelestis (Marq.) H. Smith	DCZ-H
		crassuloides Bureau et Franch.	W C China
		emergens Marq.	DCZ
		filistyla Balf.f. et Forrest ex Marq.	DZ-H
		handeliana H. Smith	DZ-H
		leucomelaena Maxim.	Himal. to N As.
		macrauchena Marq.	DCZ-H
		nannobella Marq.	D-H
		oreodoxa H. Smith	DZ-H
		phyllocalyx C.B.Clarke	E Himal.
		subtilis H. Smith	D-H
	Halenia	*elliptica D. Don*	Himal. to N As.
	Lomatogonium	*longifolium H. Smith*	DCZ-H
		oreocharis (Diels) Marq.	DZ-H
	Swertia	*sp.*	
	Veratrilla	*baillonii Franch.*	DCZ-H
Geranianaceae	*Geranium*	*donianum Sweet*	DCZ-H
		farreri Stapf	DC-H
		moupinensis Franch.	DC-H

Appendix 1
Continued

Family	Genus	Species	Distribution
Grossulariaceae	*Ribes*	*laciniatum Hook.* f. et Thoms.	H-E Himal
Labiatae	*Eriophyton*	*wallichii Buch ex Wall.*	Sino-Himal.
	Lamiophlomis	*rotata (Benth.) Kudo*	Sino-Himal.
	Salvia	*evansiana Hand.-Mazz.*	DC-H
Liliaceae	*Aletris*	*pauciflora (Klotz.) Franch.*	H-Himal
	Fritillaria	*crirrhosa D. Don*	Sino-Himal.
	Lilium	*lophophorum Bur. et.Fanch.*	DCZ-H
	Lloydia	*brevistyla ZDF,sp.nov*	
		oxycarpa Franch.	WCChina
		serotina(L.)Reichenb.	N Temp
Liliaceae	*Streptopus*	*simplex D. Don.*	H-Himal.
Onagraceae	*Chamaenerion*	*angustifolium (L.) Scop.*	N temp.
	Epilobium	*kingdonii Raven*	DZ-H
		williamsii Raven	H-Himal.
Orchidaceae	*Orchis*	*chrysea* (W.W. Smimth) Schltr	DZ-H
		chusua D. Don	Himal-N As.
Papaveraceae	*Meconopsis*	*horridula Hook. f. et Thoms. Var. racemosa (Maxim.) Prain*	W C China
		impedita Prain	DZM-H
		integrifolia (Maxim.) Franch. Var. integrifolia	H
		lancifolia (Franch.) Franch. Ex Prain	H
		speciosa Prain	DCZ-H
Papilionaceae	*Astragalus*	*acualis Baker*	DCZ-H
		ernestii Comb.	DCZ-H
		skythropos Bunge	H-NW China
	Caragana	*jubata (Pall.) Poir.*	temp. As.
	Chesneya	*nubigena (D. Don) Ali*	H-Himal.
	Hedysarum	*limitanaeum Hand.-Mazz.*	DZ-H
	Thermopsis	*smithiana Piter-Stib.*	DCZ-H
	Tibetia	*yunnanensis (Franch.) Tsui*	DC-H
Polygonaceae	*Fagopyrum*	*leptopodum (Diels) Hedb*	DC-H
	Polygonatum	*verticillatum(L.)All.*	E-Himal.
	Polygonum	*calostachyum Diels*	H-Himal.
		forrestii Diels	SW China
		longisetum De Br.	N & C China
		macrophyllum D. Don	W C China
		nummularifolium Meisn.	H-Himal.
		sparsipilosum A. J. Li	W C China
		tinctorium Ait.	China
		viviparum L.	
	Rheum	*delavayi Franch.*	
		forrestii Diels	
		pumilum Maxim.	DCZQG

Appendix 1
Continued

Family	Genus	Species	Distribution
Primulaceae	*Androsace*	*delavayi Franch.*	DCZ
		minor (Hand. - Mazz.) C.M. Hu et Y.C. Yang	C(new distribution in D)
		stenophylla (Petitm.) Hand. - Mazz.	CZ(new distribution in D)
		tapete Maxim.	WCChina-H
		triolaba Balf. F. ex Forr.	
		zambalensis (Petitm.) Hand.-Mazz.	DCZQ-H
	Omphalogramma	*serratifolia Franch.*	
		souliei Franch.	DCZ
		vincaeflora (Franch.) Franch.	DCZG
	Primula	*amethystina Franch. ssp. brevifolia (Forr.) W. W. Smith & Forrest*	DCZ
		bella Franch.	DCZ
		blinii Levl.	DC
		calliantha Franch. subsp. bryophila (Balf. f & Farrer.) W.W. Smith & Forrest	DZ-H
		dryadifolia Franch.	DCZ
		gemmifera Batal var. amoena Chen	DC
		involucrata ssp. yargongensis (Petitm.) W.W. Smith & Forr.	DCZ
		pinnatifida Franch.	DC
		pulchella Franch.	DCZ
		silaensis Petitm.	DZ-Himal.
		sinopurpurea Balf. f. ex Hutch.	DCZ
Ranunculaceae	*Aconitum*	*pulchellum Hand.-Mazz.*	H-Himal.
	Anenome	*demissa?Hookl.f.et Thoms. var.villosissma Bruhl*	Sino-Himal.
		obtusiloba D. Don ssp. ovalifolia Bruhl	H-Nchina
		trullifolia Hook. f. et Thoms.	H-Himal.
	Caltha	*palustris Linn.*	N Temp
	Clematis	*chrysocoma Franch.*	SWChina
	Delphinium	*beesianum W.W. Smith*	DCZ-H
		forrestii Diels.var.forrestii	DC-H
		hui Chen	DC-H(new distribution in D)
		pergameneum W.T.Wang	D-H(Deqin)
	Oxygraphis	*delavayi Franch.*	DCZ-H
		glacialis(Fisch.exDC.) Bunge	Himal.to Sibiria Sino.
	Paraquilegia	*microphylla(Royle) Drumm.et Hutch*	Himal.to NAs.
	Ranuculus	*glacialiformis Hand.-Mazz.*	H-Himal.
		glareosus Hand.-Mazz.	H
		hirtellus Royle var.orientalis W.T.Wang	H
		pseudopygmaeus Hand.-Mazz.	H-Himal.
		tanguticus(Maxiim.) Ovcz.in Kom.	Sino-Himal.
	Thalictrum	*alpinum L.*	Sino-Himal.
		delavayi Franch.	SWChina
		squamiferum Lecoy.	H-E Himal.
	Trollius	*farreri Stapf*	H
Rosaceae	*Cotoneaster*	*rotundifolius Wall.ex. Lindl.*	DCZ-H
	Fragaria	*orientalis Loginsk.*	Temp.As.
	Potentilla	*ancistrifolia Bge.Mem. Acad.Sci.St.Petersb*	SW to Nchina
		coriandrifolia	DCZ
		cuneata Wall.	Sino-Himal.
		discolor Bge.var.minoe ZDFang.var.nov.	unknown
		eriocarpa Wall.ex Lehm. var.tsarongensis W.E.Evans	DCZ
		fruticosa L.var.albicans Rehd.et Wils.	SW to Nchina
		glabra Lodd.Bot Cab.	Temp.As.
		gracillima Yu et Li	Z(new distribution in D)
		leuconota D. Don	Sino-Himal.
		peduncularis D. Don	Sino-Himal.
		penducularis D. Don var. abbreviata Yu et Li	Sino-Himal.
		penducularis D. Don var. penducularis	Sino-Himal.
		saundersianaRoyle var. caespitosa(Lehm.)Wolf	SW to Nchina
		saundersianaRoyle var.saundersiana	Sino-Himal.
		stenophylla(Franch.)Diels	DCZ
		taliensis W. W. Smith	D-H
	Rubus	*subinopertus Yu et Lu*	DCZ
	Sibbaldia	*cuneata Hornem. Ex Ktze.*	N As. & Taiwan
		pentaphylla J. Krause	DCZQ
		pulvinata Yu et Li	DZ-H
	Sorbus	*prattii Koehne*	DCZ-H
		reducta Diels	DC-H
Salicaceae	*Salix*	*faxoninaoides C.Wang et P.Y.Fu*	DZ-H
		oreinoma Schneid.in Sarg.	DCZ-H
		paraflabellaris.S.D.Zhao	D-H
		piptotricha Had.-Mazz.	D-H

Appendix 1
Continued

Family	Genus	Species	Distribution
		sclerophylla Andress.	DCZQG-H-Himal.
Saxifragaceae	*Bergenia*	*purpurascens*	H-Himal.
	Chrysosplenium	*nudicaule*	Himal. to N As.
		sp.	
	Parnassia	*chinensis Franch.*	E Himal.
		pusilla Wall.	E Himal.
		sp.	
		viridiflora Batalin	W C China
	Ponencia	*sp.*	
	Saxifraga	*aristulata Hook.f. et Thoms.*	H-Himal.
		brachypoda D. Don	H-Himal.
		ciliatopetala (Engl. Et Irmsch.) J. T. Pan	H-Himal.
		diversifolia	H-Himal.
		elatinoides	DC-H
		forrestii	D-H
		heteroclada H. Smith	DZM-H
		heterocladoides J. T. Pan	DZ-H
		heterotricha	DZ
		hispidula	H-Himal.
		hypericoides Franch.	DC-H
		melanocentra	Sino-Himal.
		microgyna Engl. Et Irmsch.	DCZQ-H
		montana H Smith	DCZQG-H
		mucronulata Royle	H-Himal.
		nanelloides	D-H
		peplidifolia Franch.	D-H
		pulchra Engl. et Irmsch.	D-H
		sinomontana	
		sp.	
		sp.2	
		stella-aurea	H-Himal.
		stenophylla	Sino-Himal.
		wardii	DZ-H
		yunlingensis C. Y. Wu	D-H
Scrophulariaceae	*Lagotis*	*alutacea W. W. Smith var. rockii (Li) Tsoong*	DC-H
		praecox W. W. Smith	DC-H
	Lancea	*hirsuta Bonati*	DC-H
	Pedicularis	*debilis Franch.*	D-H
		dolichocymba Hand.-Mazz.	DCZ-H
		elwesii Hook. f.	H-E Himal.
		integrifolia Hook.f. subsp. Integerrima (Pennell et Li) Tsoong	DC-H
		likiangensis Franch. subsp. pulchra Tsoong	D-H
		myrtillus	
		neolatituba Tsoong	DC-H
		oederi Vahl var. sinensis (Maxim.) Hurus	W C China
		praeruptorum Bonati	D-H
		przewalskii Maxim. subsp. australis (Li) Tsoong	DZ-H
		pseudoversicolor Hand.-Mazz.	D-H
		roleyi Maxim.	H-Himal.
		rupicola Franch. Ex Maxim.	DC-H
		tsekouensis Bonati	DC-H
	Picrohiza	*scrophulariiflora Pennell*	H-Himal.
	scrophularia	*hypsophila Hand.-Mazz.*	D-H
Umbelliferae	*Acronema*	*wolffianum Fedde ex Wolff*	H-Himal.
	Blupeurnum	*commelynoideum de Boiss.*	DCZ-H
	Chamaesium	*paradoxum Wolff*	DCZ-H
		viridiflorum (Franch.) Wolff ex Shan	D-H
	Ligusticum	*involucratum Franch.*	DC-H
	Physospermopsis	*shaniana C. Y. Wu et Pu*	DCZ
	Pleurospermum	*davidii Franch.*	DCZ-H
		govanianum (Wall. ex DC.) Benth ex C. B. Clarke	DCZ-H
		hookeri C. B. Clarke var. thomsonii C. B. Clarke	C As to China
		nanum Franch.	DCZ-H
	Sanicula	*elata Buch.-Ham.*	As. to Afr.
	Sinocarum	*cruciatum (Franch.) Wolff var. linearilobum Franch.*	DCZ-H
		filicum Wolff	DCZ-H
		pauciradiatum Shan et Pu	DCZ-H
	Sinolimprichita	*alpina Wolff var. dissecta Shan et S. L. Liou*	DCZ-H
	Trachydium	*kindon-wardii Wolff*	DZ-H
		rockii Wolff	D-H
	Vicatia	*coniifolia (Wall) DC.*	H-Himal.
Valerianaceae	*Nardostachys*	*jatamansi (D. Don) DC.*	DCZ
Violaceae	*Viola*	*rockiana W. Beck*	DCZQ-H
Zingiberaceae	*Roscoea*	*tibetica Bat.*	DCZ-H

D = Dian (Yunnan); C = Central, Chuan (Sichuan); Z = Xizang (Tibet); H = Yunnan Hengduan Mts; Q = Qinghai; M = Myanmar; G = Gansu; Himal. = Himalayas.

References

Anderson DM, Salick J, Moseley RK, Ou X (2005) Conserving the sacred medicine mountains: a vegetation analysis of Tibetan sacred sites in Northwest Yunnan. *Biodivers Conserv* **14**: 3065–91.

Baker B, Moseley R (2007) Changes in the Hengduan Mountains: advancing treeline and retreating glaciers. *Arct Antarct Alp Res* **39**:200–9.

Biondini ME, Bonham CD, Redente EF (1985) Secondary successional patterns in a sagebrush (Artemisia tridentate) community as they relate to soil disturbance and soil biological activity. *Vegetatio* **60**:25–36.

Bowman WD, Damm M (2002) Causes and consequences of vascular plant diversity in the Rocky Mountains. In: Korner Ch, Spehn EM (eds). *Mountain Biodiversity: A Global Assessment*. New York: The Parthenon Publishing Group, 35–48.

Buntaine MT, Mullen RB, Lassoie JP (2007) Human use and conservation planning in alpine areas of northwestern Yunnan, China. *Environ Dev Sustainability* **9**:305–24.

Byers A (2005) Contemporary human impacts on alpine ecosystems in the Sagarmatha (Mt. Everest) National Park, Khumbu, Nepal. *Ann Assoc Am Geogr* **95**:112–40.

Chao A, Chazdon RL, Colwell RK, Shen T (2005) A new statistical approach for assessing similarity of species composition data with incidence and abundance data. *Ecol Lett* **8**:148–59.

Chapin FS III, Körner CH (eds) (1995) *Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences*. Berlin, Germany: Springer.

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. *Aust J Ecol* **18**:117–43.

Colwell RK (2005) *EstimateS: Statistical Estimation of Species Richness and Shared Species from Samples. Version 7.5. User's Guide*. http://purl.oclc.org/estimates. (5 May 2008, date last accessed).

Crawley MJ (2002) *Statistical Computing: An Introduction to Data Analysis Using S-Plus*. West Sussex, UK: John Wiley and Sons, Inc.

Deng M, Zhou ZK (2004) Seed plant diversity on screes from northwest. *Yunnan Acta Botanica Yunnanica* **26**:23–34.

Dufrene M, Legendre P (1993) Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol Monogr* **67**:345–66.

Foggin M, Smith AT (1996) Rangeland utilization and biodiversity on the alpine grasslands of Qinghai Province, People's Republic of China. In: Peter JS, Wang S, Xie Y (eds). *Conserving China's Biodiversity (II)*. Beijing, China: China Environmental Science Press, 247–58.

Gaetz R (2002) Great rivers of Yunnan: conservation in a changing China. *Nat Conserv Mag* **49**:10–17.

Ge XJ, Zhang LB, Yuan YM, Hao G, Chiang TY (2005) Strong genetic differentiation of the East-Himalayan *Megacodon stylophorus* (Gentianaceae) detected by inter-simple sequence repeats (ISSR). *Biodivers Conserv* **14**:849–61.

Gibson LA, Wilson BA, Aberton JG (2004) Landscape characteristics associated with species richness and occurrence of small native mammals inhabiting a coastal heathland: a spatial modeling approach. *Biol Conserv* **120**:75–89.

Guan KY, Zhou Z, Hang S, Yong F, Weibang S (1998) *Highland Flowers of Yunnan*. Yunnan, People's Republic of China: Kunming Institute of Botany, Chinese Academy of Sciences. Yunnan Science and Technology Press.

Guo HJ, Long CL (1998) *Yunnan's Biodiversity*. Kunming, China: Yunnan Science and Technology Press (in Chinese).

Hadley KS (1987) Vascular alpine plant distributions within the central and southern Rocky Mountains, USA. *Arct Alp Res* **19**: 242–51.

Hall K, Boelhouwers J, Driscoll K (1999) Animals as erosion agents in the alpine zone: Some data and observations from Canada, Lesotho, and Tibet. *Arctic, Antarctic and Alpine Research* **31**:436–446.

IUCN *Three Parallel Rivers of Yunnan Protected Areas*. http://whc.unesco.org/en/list/1083. (5 May 2008, date last accessed).

Körner Ch (2000) The alpine life zone under global change. *Gayana Bot* **57**:1–17.

Körner Ch (2003) *Alpine Plant Life. Functional Plant Ecology of High Mountain Ecosystems*, 2ndedn. Berlin, Germany: Springer-Verlag.

Ma C, Moseley RK, Chen W, Zhou Z (2007) Plant diversity and priority conservation areas of Northwestern Yunnan, China. *Biodivers Conserv* **16**:757–74.

McCune B, Mefford MJ (1999) *PC-ORD. Multivariate Analysis of Ecological Data. MjM Software Design*. Gleneden Beach, Oregon.

McGarigal K, Cushman S, Stratford S (2000) *Multivariate Statistics for Wildlife and Ecology Research*. New York: Springer-Verlag.

McNab WH (1989) Terrain shape index: quantifying effect of minor landforms on tree height. *For Sci* **35**:91–104.

Meihe G (1997) Alpine vegetation types of the central Himalaya. In: Wiegolaski FE (ed). *Ecosystems of the World 3. Polar and Alpine Tundra*. Amsterdam: Elsevier The Netherlands161–84.

Miller DJ (1999) Herders of forty centuries: nomads of Tibetan Rangelands in Western China. Townsville, Australia402–3People and Rangelands: Building the Future, Proceedings of the VIth International Rangeland Congress, July 17–23, 1999.

Miller DJ (2002) Pastures of Plenty? Livestock Grazing and Conservation of Himalayan Rangelands. In: Wikramanayake ED, Dinerstein E, Loucks C, Olson D, Morrison J, Lamoreux J, Mcknight M, Hedao P (eds). *Terrestrial Ecoregions of the Indo-Pacific: A Conservation Assessment*. Washington, DC.: Island Press.

Mittermeier R, Meyers N, Mittermeier N, Gil P, Ford H (1999) *Hot Spots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Mexico City, Mexico: Cemex, Conservation Int.

Moseley RK (2006) Historical landscape change in Northwestern Yunnan, China. *Mt Res Dev* **26**:214–9.

Riebesell JF (1982) Arctic-alpine plants on mountaintops: agreement with island biogeography theory. *Am Nat* **119**:657–74.

Salick J, Anderson JD, Woo J (2004) Tibetan ethnobotany and gradient analysis: Menri (Medicine Mountains), Eastern Himalayas. *The Millenium Ecosystem Assessment. Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Multi-Scale Assessments*. Alexandria: Egypt http://www.millenniumassessment.org/documents/bridging/papers/salick.jan.pdf. (5 May 2008, date last accessed).

Sherman RE, Mullen R, Li H, Fang Z, et al (2007) Alpine ecosystems of Northwest Yunnan, China: an initial assessment for conservation. *J Mt Sci* **4**:188–92.

Tang Z, Wang Z, Zheng C, Fang J (2007) Biodiversity in China's Mountains. *Front Ecol Environ* **4**:347–52.

TNC *The Nature Conservancy in China*. http://www.nature.org/wherewework/asiapacific/china/work/art5098.html. (5 May 2008, date last accessed).

Vare A, Lampinen R, Humphries C, et al (2003) Taxonomic diversity of vascular plants in the European alpine areas. In: Thompson DBA (ed). *Alpine Biodiversity in Europe*. Heidelberg, Germany: Springer-Verlag, 133–48.

Walker M, Walker D, Theodose T, et al (2001) The vegetation: hierarchical species-environment relationships. In: Bowman WD, Seastedt TR (eds). *Structure and Function of an Alpine Ecosystem*. New York: Oxford University Press, 99–127.

Wilkes A (2006) Innovations to support agropastoralist livelihoods in Northwest Yunnan. *Mt Res Dev* **26**:209–13.

Wilson BA, Aberton JG, Reichl T (2001) Effects of fragmented habitat and fire on the distribution and ecology if the swamp antechinus (*Antechinus minimus maritimus*) in the eastern Otways, Victoria. *Wildl Res* **28**:527–36.

Xu J, Fox J, Lu X, et al (1999) Effects of Swidden Cultivation, State Policies, and Customary Institutions on Land Cover in a Hani Village, Yunnan, China. *Mt Res Dev* **19**:123–32.

Xu J, Wilkes A (2003) Biodiversity impact analysis in northwest Yunnan, southwest China. *Biodivers Conserv* **13**:959–83.

Yi S, Wu N, Luo P, et al (2007) Changes in livestock migration patterns in a Tibetan-style agropastoral system. *Mt Res Dev* **27**: 138–45.