Journal of Mountain Science Vol **4** No 3 (2007): 181~192
http://jms.imde.ac.cn

DOI: 10.1007/s11629-007-0181-6

Alpine Ecosystems of Northwest Yunnan, China: an Initial Assessment for Conservation

Ruth Sherman

Department of Natural Resources, Cornell University, Ithaca, NY 14853, USA
Corresponding author, E-mail: Ruth Sherman res6@cornell.edu

Renee Mullen

The Nature Conservancy, Boise, ID, 83702, USA

LI Haomin

The Nature Conservancy, China Program, Kunming, Yunnan, PRC

FANG Zhendong

Shangri-la Alpine Botanical Institute, Zhongdian, Yunnan, PRC

WANG Yi

State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany,
The Chinese Academy of Sciences, Beijing, PRC

Abstract: Implementing conservation actions on-the-ground is not a straightforward process, especially when faced with high scientific uncertainty due to limited available information. This is especially acute in regions of the world that harbor many unique species that have not been well studied, such as the alpine zone of the Hengduan Mountains of Northwest Yunnan (NWY), a global biodiversity hotspot and site of The Nature Conservancy's Yunnan Great Rivers Project. We conducted a quantitative, but rapid regional-level assessment of the alpine flora across NWY to provide a broad-based understanding of local and regional patterns of the alpine flora, the first large-scale analysis of alpine biodiversity patterns in this region. Multivariate analyses were used to classify the major plant community types and link community patterns to habitat variables. Our analysis indicated that most species had small distributions and/or small population sizes. Strong patterns emerged with higher diversity in the more northern mountains, but beta diversity was high, averaging only 10% among sites. The ordinations indicated that elevation and geographic location were the dominant environmental gradients underlying the differences in the species composition among communities. The high beta diversity across the alpine of these mountains implies that conservation strategies ultimately will require the protection of large numbers of species over a large geographical area. However, prioritization should be given to areas where potential payoffs

Received: 5 June 2007
Accepted: 23 July 2007

are greatest. Sites with high species richness also have a greater number of endemic species, and, by focusing efforts on these sites, conservation investments would be maximized by protecting the greatest number of unique species.

Keywords: Biodiversity hotspot; cluster analysis; plant community ecology; conservation action; grazing; Hengduan Mountains; non-metric multidimensional scaling; plant species richness; World Heritage Site; Yunnan Great Rivers Project (YGRP); alpine ecosystems; China

Introduction

With the accelerating loss of species and habitats throughout the world, the conservation community is looking for approaches that can maximize efforts to protect biodiversity. Global biodiversity hotspots have been identified as one means to prioritize conservation efforts in an arguably efficient and cost-effective way that safeguards the greatest number of species per unit of conservation area, and presumably, investment (Olson and Dinerstein 1998, Mittermeier et al. 1999, Myers et al. 2000). However, implementing conservation actions on-the-ground remains a challenge for conservation organizations and natural resource managers (Groves et al. 2000, Ma et al. 2007). Levels of diversity, viability, endemism, rare species and threats are not distributed evenly across large geographic regions, and decisions on how to prioritize protection efforts within a biodiversity hotspot is an on-going struggle for conservation planners. Such issues are particularly acute when urgent conservation actions are needed, but basic data on species distributions and diversity are not available.

The mountains of south-central China have been identified as a global conservation priority for plant diversity (Barthlott et al. 1996, Klotzi 1997, Olson and Dinerstein 1998, Boufford and Dijk 1999, Myers et al. 2000, CI 2006). Within this hotspot lie the southern Hengduan Mountains, the focus of a joint conservation project initiated in 1999 by the Yunnan Provincial Government and the Nature Conservancy: the Yunnan Great Rivers Project (YGRP). Due to the paucity of biodiversity data from this area and the need for quick action because of the rapid pace of development in China, experts were asked to identify priorities for conservation investment (YGRPPT 2002, Ma et al. 2007). The entire alpine zone was subsequently categorized as an important conservation priority because of its high species richness, endemism, threats, and value to local communities (YGRP 2001, Xu and Wilkes 2003, Deng and Zhou 2004, Salick et al. 2004, Baker and Moseley 2007, Buntaine et al. 2006). However, because the alpine zone, covering roughly 12 % (8200 km^2) of the project area, is such a large and widely distributed habitat type, it was clear that the decision to invest in on-the-ground action would require additional information.

To address these needs, TNC-China initiated the Alpine Ecosystem Project in 2003, a collaborative effort among community, government and research institutions with the long-term goal of protecting and promoting the sustainable use of the alpine (TNC 2006). It was recognized that effective conservation strategies would require an understanding of the ecology of the alpine, how local people use and manage this resource, and how the broader and more ubiquitous threat of climate change might impact these relationships. An unique integrated research approach was used whereby sociologists (Buntaine et al. 2006), climate change experts (Baker and Moseley 2007, Baker et al. 2005) and plant ecologists (this study) spent much of the 2004 field season visiting alpine sites together to gather complementary data on a suite of alpine ecosystems across a broad geographic range. The cumulative results will provide the basis for selecting critical alpine habitats across NWY and for designing and implementing conservation strategies at the site level and broader regional scale.

The goal of this study was to conduct a quantitative, but rapid regional-level assessment of the alpine flora across NWY to provide a broad-based understanding of local and regional patterns of the alpine vegetation to help prioritize conservation efforts across this vast landscape. Our specific objectives were the following: 1) Determine how alpine plant species richness and composition vary across the mountains of NWY; 2) Examine the relationships between biotic and abiotic characteristics with plant species richness and composition; and 3) Assess the current health and status of the alpine with regard to human land use. This is the first large-scale analysis of vegetation patterns in the alpine ecosystems across the Hengduan Mountains of NWY, a critical first step for setting geographic priorities for conservation actions. The study was designed by researchers and conservation managers working together to ensure that a pragmatic but rigorous approach was employed that would efficiently address urgent conservation questions.

1 Study Site

This study was conducted in the southern Hengduan Mountains in the northwestern region of Yunnan Province in Southwest China. The study area extended 310 km from north to south (29°00' ~ 25°30'N) and 180 km from east to west (98°05' ~ 100°15'E) bordering the Yunnan-Tibet border in the north, the Yunnan-Sichuan border in the east, the Sino-Burma border in the west (Figure 1). Three major Asian rivers, the upper Yangtze (Jinsha), Mekong (Lancang) and Salween (Nu), have carved deep parallel gorges that run north to south through these 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. Across this steep environmental gradient, life zones range from subtropical in the canyon bottoms to temperate forests, boreal forests, arctic-alpine vegetation and permanent ice and snow. The Indo-Malayan and Palaearctic biogeographic realms have converged across this complex and diverse landscape to create this epicenter of biodiversity that is one of the most biologically diverse temperate ecosystems on earth (Mittermeier et al. 1999, Myers et al. 2000). This unique ecoregion represents one of the world's 26 hotspots of biodiversity (Mittermeier et al. 1999) and was recently designated as a World Natural Heritage Site (http://whc.unesco.org/en/list/10 83).

The prevailing climate is monsoonal with wet summers and dry winters with most precipitation falling between June and September (Bandyopadhyay 1992). There is a general trend of decreasing precipitation from the southeast to northwest but patterns vary considerably across the region with annual precipitation ranging from 300 ~ 950 mm (OSU-SCAS 2006). The mean annual temperature above 4100 m is below 0°C and many of the higher peaks are covered by snow year round.

The alpine, defined here as the vegetated area above treeline (Körner 2003), is located generally between 4000 ~ 5000 m of elevation and constitutes about 12 % of this mountainous area. The high elevation alpine has the most diverse array of plant species in the Meili Mountains as compared to the lower elevation forest ecosystems, including many rare and endangered species, a high number of endemics, and many species important in traditional Tibetan medicine (Salick et al. 2004, Xu and Wilkes 2003). In addition to their high biodiversity value, alpine ecosystems have important social and economic significance to local people. The largely Tibetan population of NWY has grazed livestock, primarily yak, in alpine meadows for millennia and nomadic pastoralism continues to be their most important livelihood today (Wu 1997a, Zhao and Zhou 1999). More recently, the government has targeted underdeveloped western China for economic expansion as part of their poverty alleviation program, and NWY currently is experiencing rapid economic growth (ADB 1999). As a result, traditional land use systems are changing as subsistence systems shift to a cash economy. Market driven changes pose novel threats to the biodiversity of the region (Xu and Wilkes 2003).

2 Methods

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 (Figure 1) with the assumption 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 overlaid on a map of the alpine (areas between 4000 ~ 5000 m) of NWY. To locate a site on the ground, we identified the village that held traditional grazing rights to the alpine area of interest, traveled to the village and hired a local guide who could lead us to alpine area, and then used a GPS to locate the sample site.

Within each 1-km² site, the three major alpine vegetation community types were sampled: 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). Two 50-m long transects with ten 1-m² subplots were located within each community type at each sampling site for a total of 6 transects per site. A total of 60 m² was sampled per site. A standardized sampling approach with equal sampling effort was employed to allow for the direct comparison of vegetation attributes among sites. Field surveys were carried out from June through mid-October 2005.

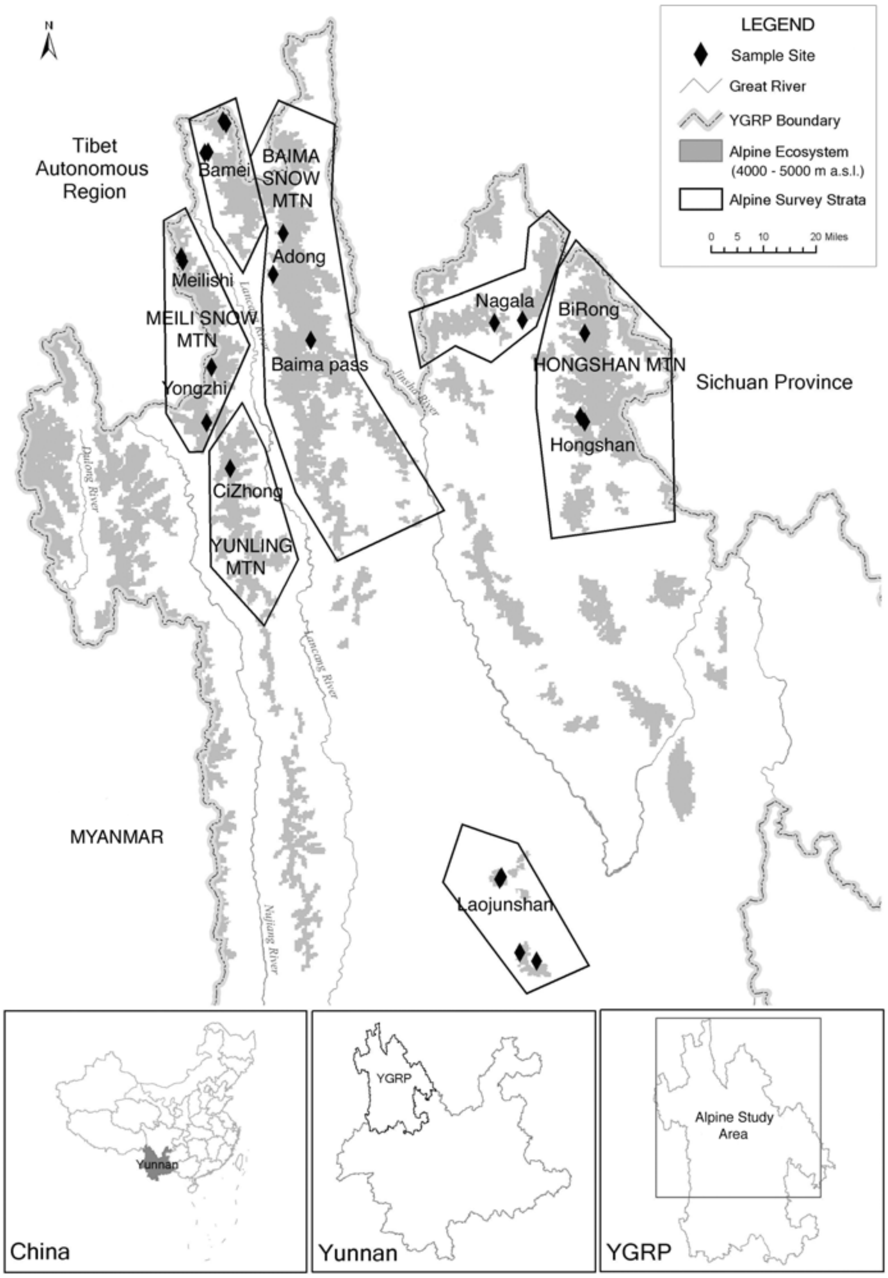

Figure 1 Map showing the location of the Yunnan Great Rivers Project in northwest Yunnan, China. The diamonds represent the 21 alpine sampling sites, and the polygons represent the different strata used in the stratified random sampling design.

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 using nine vegetation cover classes. All grasses, including grasses, sedges and rushes, were lumped into one category and given a percent cover class. Also, the percentage of bare ground (disturbed, open soil) and rock (the amount of exposed rock) that covered each sample plot was recorded using the same cover classes as for the vegetation, and average height of the meadow vegetation was recorded in each subplot as a measure of vegetation structure. In addition to the vegetation data, environmental data were collected for each transect including elevation, slope gradient, aspect, terrain shape index (McNab 1989) and slope position (ridge top to valley bottom).

All species were described in the field and specimens were collected for later identification. 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.

The total numbers of species, genera and families were tallied for each transect and site, and species richness was compared among and within community types (shrub, meadow, scree) and strata (sites as replicates within strata) using a Kruskall-Wallis test for *k* independent samples in S-Plus 6.2.

Multivariate analyses were used to classify the major plant communities 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. Rare species, those that occurred in ≤ 2 sample transects, were not included in the analyses. Cluster analysis was applied to the vegetation data to combine transects with similar species into alpine plant community groups (McCune and Mefford 1999, McCune and Grace 2002). Non-metric multidimensional scaling (NMS) (Kruskal 1964, Mather 1976, Clarke 1993) was used to graphically examine the arrangement of plots based on species composition in relationship to measured environmental parameters.

Jaccard's coefficient of similarity (J) was used to measure species overlap between communities among all sites (210 pairwise comparisons) using EstimateS software (Colwell 2005).

3 Results

A total of 21 sites and 109 transects consisting of 31 meadow, 40 shrub, and 38 scree communities were sampled from seven strata (Figure 1). We sampled as many sites as possible given time constraints imposed by the logistics of traveling by foot to remote sites and sampling time in the field. Some of the randomly selected sites were not accessible: there was no water available at the site; the site was too remote requiring too many days of travel; or the site was off-limits to foreigners because it was located on a sacred mountain. Given these constraints, we attempted to select a suite of sites across a broad geographic region so as to get a representative picture of the alpine ecosystems across NWY. 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, island-like peaks of the Laojunshan mountains (Figure 1; Table 1). The sites are labeled according to their administrative village names or local names.

3.1 Species richness

A total of 369 species from 40 families and 116 genera were collected. Uncommon species, those occurring at only one site, accounted for 38 % of the total species and those occurring at ≤ 2 sites accounted for 58 % of the total species encountered (Figure 2). Species richness varied greatly among sites (no. species / 60 m^2), ranging from 19 to 105 species with an average of 59 species per site (Table 1). Genus richness ranged from 15 to 64 and averaged 38 genera per site, and family richness ranged from 12 to 31 and averaged 23 families per site (Table 1). The majority of species encountered in this study were endemic to the Hengduan Mountains (64 %) and 15 % were endemic just to Northwest Yunnan. The greatest concentration of

NWY endemics was found in the Baima and the northern Meili Snow Mountains (27 species), with 21 endemic species in the northeastern mountain ranges, 13 species in the Yunling and southern Meili mountains and 10 in the Laojunshan mountains.

Average species richness per site was significantly different among the seven sampling strata ($X^2 = 13.30$, p=0.0371) with richness greatest in the Baima Snow Mountains and lowest in the sites of the Laojunshan sites in the south (Figure 3).

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

Site Name	Site #	Date Sampled	Average Elevation (m)	Approximate Location		Richness (#/60m²)		
				UTM-north	UTM-east	Species	Genus	Family
BiRong	1	1-Jun-04	4640	3139255	47588771	47	28	20
CiZhong	2	27-Jun-04	4130	3097605	47479704	42	29	18
BaMei	3	6-Jul-04	4457	3195112	47472896	40	32	23
BaMei	4	8-Jul-04	4327	3194906	47471832	46	34	24
BaMei	5	12-Jul-04	4698	3204756	47477560	51	36	20
BaMei	6	14-Jul-04	4668	3203946	47478472	47	31	23
Adong	7	8-Aug-04	4558	3170108	47495946	88	53	28
Adong	8	12-Aug-04	4588	3157481	47492946	95	58	31
Meilishi	9	21-Aug-04	4513	3162879	47464616	105	55	26
Meilishi	10	23-Aug-04	4641	3161410	47465122	83	47	24
Yongzhi	11	1-Sep-04	4238	3128855	47473889	33	25	18
Yongzhi	12	3-Sep-04	4153	3111691	47472464	71	36	20
Baima Pass	13	7-Sep-04	4503	3137119	47504462	104	64	31
Hongshan	14	11-Sep-04	4446	3111932	47588729	80	45	28
Hongshan	15	12-Sep-04	4431	3113574	47587376	74	44	27
Laojunshan	16	20-Sep-04	4159	2971184	47562578	43	34	23
Laojunshan	17	21-Sep-04	4188	2971847	47563179	19	15	12
Laojunshan	18	23-Sep-04	4120	2945966	47573901	27	19	13
Laojunshan	19	24-Sep-04	4220	2948515	47568841	39	32	21
Nagala	20	10-Oct-04	4411	3143298	47569619	50	37	20
Nagala	21	13-Oct-04	4443	3142551	47560939	64	45	23

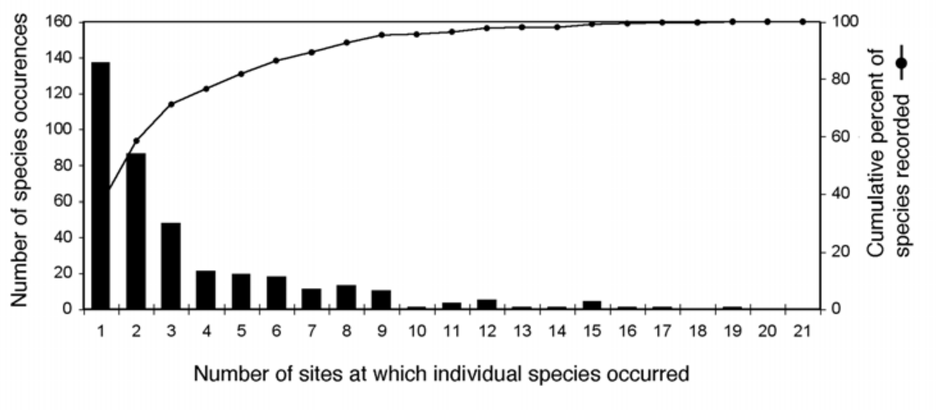

Figure 2 Frequency distribution of species occurrences at sites in alpine ecosystems of the Hengduan Mountains, northwest Yunnan, China

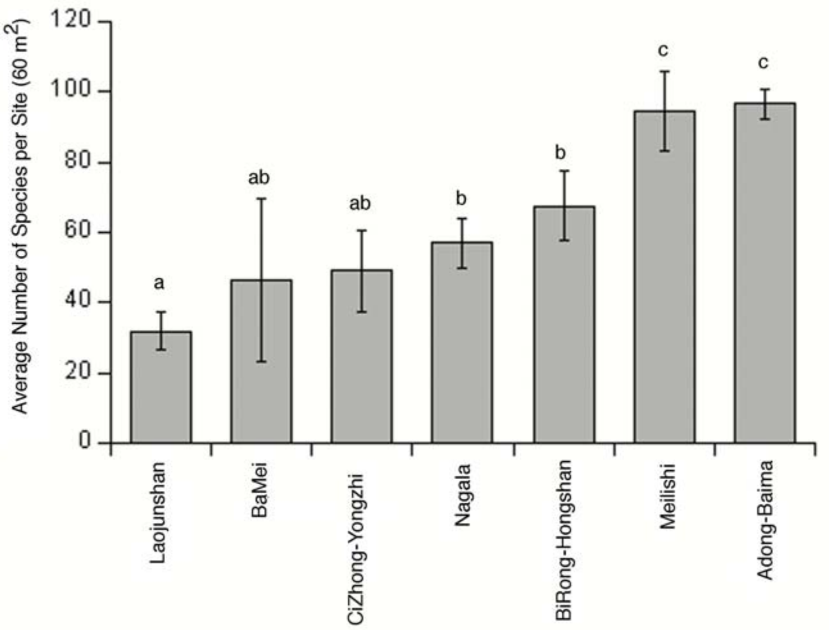

Figure 3 Average species richness of alpine ecosystems in different regions of the Hengduan Mountains, Yunnan, China. See Figure 1 for location of named areas

3.2 Species overlap among sites

The species composition of the alpine zone varied greatly among sites. Similarity in the species composition among the 40 shrub communities averaged only 11 ± 0.6 % (range 0 ~ 38 %) among all pairs of sites as calculated by Jaccard's Coefficient of Similarity. Meadow species lists overlapped by 10 ± 0.9 % among sites and ranged from 0 to 58 % among sites, and species in the scree communities overlapped by an average of 9 ± 0.5 % ranging from 0 to 40 %. The actual number of species that overlapped ranged from 0 to 27 (mean = 7.4) in the shrub, 0 to 40 (mean = 6.7) in the meadows, and 0 to 17 in the scree (mean = 3.9).

3.3 Classification and ordination of vegetation

For purposes of this paper, we present a detailed analysis of the alpine meadow communities only and briefly summarize the results of the multivariate analysis for the shrub and scree communities.

The 32 alpine meadow transects were classified into four major vegetation community groups based on the similarities in species composition and abundance; two additional community groups contained only one transect each (communities 4 and 5) indicating these had compositions that were highly unique (Figure 4). These four community groups were superimposed on the NMS ordination, and the significant habitat variables were overlaid as correlation vectors. The length and direction of the vector represent the relative importance of the variable to the axes (Figure 4). The NMS clearly distinguished the four major meadow community groups identified by the cluster analysis as indicated by their separation in the ordination space (Figure 4). Strong geographic patterns in the distribution of the flora emerged; transects in close proximity to one another tended to cluster together indicating they shared a more similar species composition. The three axes explained 83 % of the total variance in the species locations. Axis III accounted for 61.0 % of the variance and was related to elevation and the amount of grass cover of the sites. Axis I represented 14.3 % of the total variance in the species matrix and was related to the east UTM coordinate; the more eastern sites were located on the left side of the graph. These sites also had a greater amount of bare ground in each plot.

The shrub vegetation was separated into 6 community groups. The NMS ordination accounted for 60.2 % of the variation in the species composition and indicated that habitat characteristics, such as slope exposure, species richness and the amount of grass cover explained 25.1 % of the species matrix. The second important axis was related to geographic location (UTM coc vordinate) accounting for 21.9 % of the variance. Community groups dominated by junipers (*Sabina* spp.) had highly diverse herbaceous communities and occurred predominantly on south facing slopes as indicated by environmental vectors. The other four community groups were dominated by different *Rhododendron* species. These communities tended to be separated by their geographic location with the more eastern sites clearly separated from the northwestern sites.

The scree vegetation was separated into four major community groups. These were separated among the three NMS axes by the amount of exposed rock in a plot, which was related to the size of the scree substrate, and by geographic location explaining 61 % of the variance in the species composition. The sites in the eastern mountains were clearly separated from the other sites along the second axis, and the more northern, high elevation sites were separated from the lower elevation southeastern sites along the third axis.

4 Discussion

Setting conservation priorities is not a simple or straightforward process, especially when faced with high scientific uncertainty due to limited available information. This is especially acute in regions of the world that harbor many unique species that have not been well studied, such as NWY. Very little is known about the nature and structure of the alpine vegetation of the southern Hengduan Mountains of NWY – a priority conservation target in this biodiversity hotspot. Because of the rapid socio-economic changes occurring in NWY (Xu and Wilkes 2003), conservation managers are faced with a certain urgency to implement site- and regional-level action plans but lack the necessary information on which to make informed decisions. This study was designed specifically 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 the study is a coarse-scale analysis of biodiversity and species patterns, strong patterns emerged, and the results offer guidance for immediate conservation action.

Our results support previous work that demonstrated that the alpine zone of NWY contains high levels of common, rare and endemic plant species, and high overall plant diversity (Salick et al. 2004). One of the most striking findings from this study was the high beta diversity (spatial variation in species composition among sites) across the alpine region of these mountains. Prioritizing areas for further conservation investment is made difficult by the fact that no two alpine areas or mountain ranges are alike in terms of plant species, making each area unique from a conservation perspective. The strong aggregation of the alpine meadow communities within geographic regions suggests that distinct phytogeographic zones with unique alpine plant communities might exist in the different mountain regions; however, some of the high beta diversity might be explained by some species having large distribution ranges with very patchy and isolated populations (Ge et al. 2005). Conservation strategies ultimately will require the protection of large numbers of species over a large geographical area.

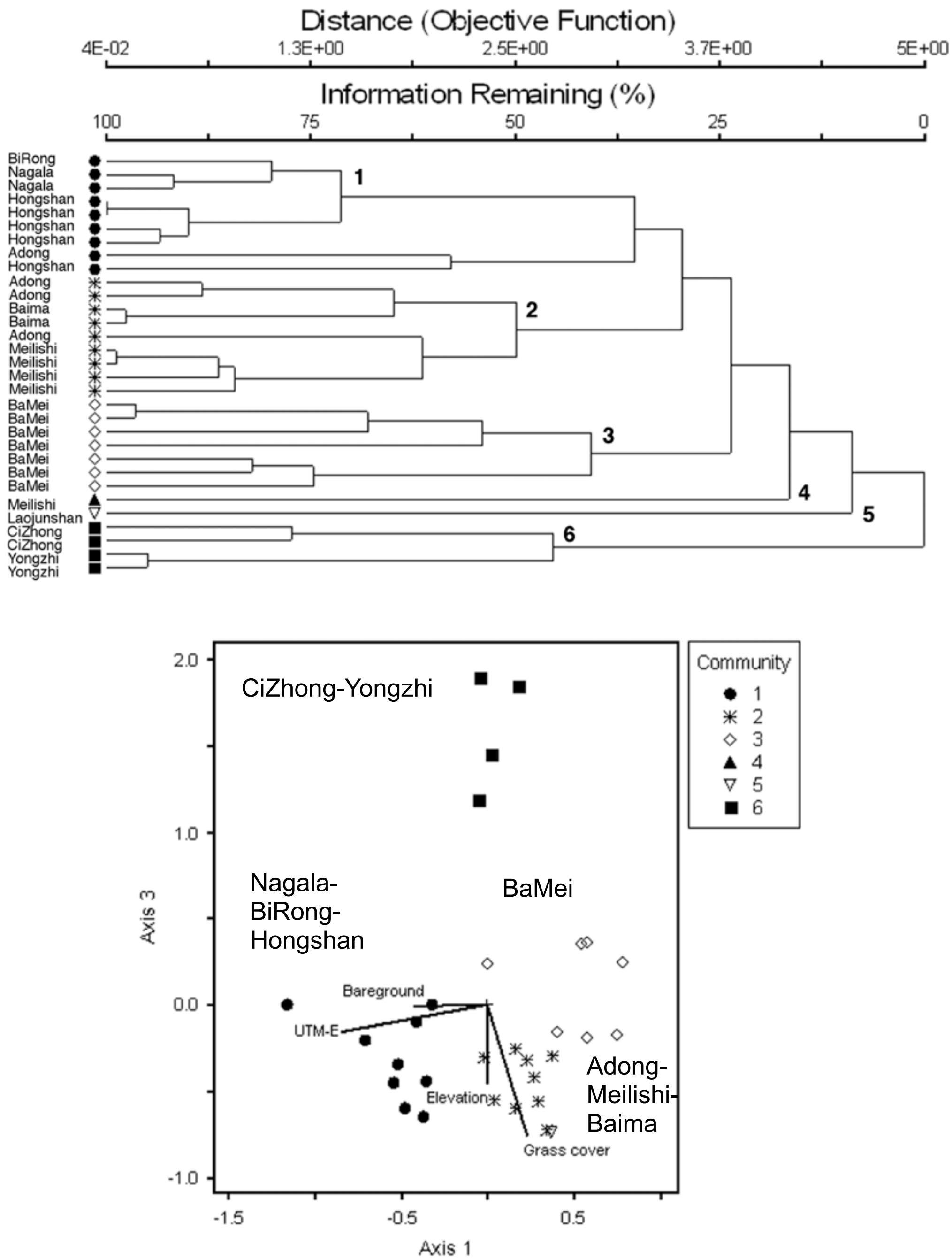

Figure 4 Results of cluster analysis and NMS ordination of 31 alpine meadow vegetation transects (10 m^2 / transect) in the Hengduan Mountains, Yunnan, China with a joint plot overlay of habitat variables. The six species assemblages identified by cluster analysis are superimposed on the ordination. See Figure 1 for the location of named areas

The data also demonstrated regional-level plant patterns in plant species richness and endemism, both of which were greatest in the more northern mountain ranges. The number of endemics at a site was positively correlated with species richness, a pattern that has been found at sites worldwide (Hobohm, 2003). Sites with a high number of endemic species can be considered as having high irreplaceability value – a site with attributes not found elsewhere (Pressey et al. 1994, Ferrier et al. 2000), and, especially if threatened, should represent a high priority for conservation (Vane-Wright 1996). Prioritization should be given to areas where potential payoffs are greatest. Sites with high species richness also have a greater number of endemic species, and, by focusing efforts on these sites, conservation investments would be maximized by protecting the greatest number of unique species. However, because there was little similarity in the species composition among sites, even the lower diversity sites, such as Laojunshan in the south, harbor unique species that most likely are not found elsewhere. In the long term, a network of sites across the landscape will be necessary to capture the spatial component of diversity and species distributions in the alpine flora.

Other factors also need to be considered when deciding where and how to invest in conserving the alpine zone – factors arguably just as important as the actual location and condition of biodiversity. These factors include the levels of current and estimated future threats to biodiversity, socioeconomic factors, such as level of importance of alpine systems and their respective ecosystem services to local people, and predicted climate change effects on alpine systems. The only potential threat we observed first hand was grazing. Grazing was prevalent throughout the mountains and clearly had an impact on the vegetation as evidenced by the dominance of low-statured species in the meadows. However, the plant species data did not suggest a problem in the form of dominance by a few nuisance or unpalatable species, indicators of over-grazing (Miller 2000, Mohamed-Saleem and Wuldo 2002, Erschbamer et al. 2003). Moreover, there was little bare soil or evidence of erosion. Large areas of exposed and eroded soil would indicate over grazing (Miller 2000), but the amount of bare ground in plots typically was less than 2 % of the area sampled. Our plant data were consistent with the views of local herders who indicated that there has been little degradation in the pasturelands above treeline over the years (Buntaine et al. 2006).

Of greater concern by local herders was the encroachment of shrubs onto traditional high elevation summer pasturelands and the subsequent loss of grazing lands (Buntaine et al. 2006). A national level burn ban instituted in 1998 to protect lower elevation forests was universally applied to all ecosystems throughout the mountains. Fire is a traditional land management tool used by herders to keep alpine pastures open and promote the growth of palatable species (Meihe 1997, Xu and Wilkes 2003, Buntaine et al. 2006). Baker and Moseley (2007) found that a change in the fire regime, along with a warming climate, were important factors contributing to an advancing treeline and the establishment of shrubs above current elevational distributions. With less alpine meadow, highland pasturing could become concentrated into smaller areas with potentially detrimental affects. Grazing can enhance biodiversity (e.g. Körner 2000). 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 (Meihe 1997). Our vegetation data suggest that fire also helps to maintain the rich diversity of the alpine meadows. Although it was evident from our observations that fire continues to be used in many parts of the region, it is perhaps at a more limited scale than historically. A combination of grazing and fire may be the important factors that contribute to biological diversity of these plant communities.

The complementary research approach utilized in the Alpine Ecosystem Project (TNC 2006) provides a more holistic view of the current condition, uses and issues concerning the alpine by integrating vegetation, socio-economic and climate change data. Thus, the biodiversity and species distribution patterns documented in this study can be evaluated within a larger framework to help prioritize sites for immediate conservation action. Understanding the social and physical context in which species and communities occur is essential for conserving these ecosystems. Regional differences in climate, geology and soils combined with topographical differences among mountain ranges appear to play a large role in influencing the species composition across the mountains of NWY. Superimposed on these environmental gradients are land use systems that have been in place for millennia. The alpine mosaic is the product of long-term ecological and social forces, and controversial issues such as grazing and the use of fire need to be addressed within a historical and conservation context. 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.

Acknowledgements

We thank The Nature Conservancy's China Program who funded this study and provided the logistical support that made the work possible. We are especially grateful to SHEN Qinggeng, CHUNG Wei and YANG Zhongyou of Yunnan University for their help in the field. Peter Kareiva provided many useful suggestions on an earlier version of this manuscript.

References

Baker, B., Moseley, R. 2007. Changes in the Hengduan Mountains: Advancing treeline and retreating glaciers. Arctic, Antarctic and Alpine Research **39**: 200 ~ 209.

Baker, B., Bachelet, D., Daly, C., Jian, M., Moseley, R., Xuezheng, S., Shlisky, A., Jihua, S. 2005. (http://conserveonline.org/docs/2006/02/Baker_et_al_2005_GLOCHAMORE .pdf)

Bandyopadhyay, J. 1992. The Himalaya: Prospects for and constraints on sustainable development. In: Stone, P.B. The State of the World's Mountains (ed.), Pp. 93 ~ 126. Zed Books Ltd., London and New Jersey.

Barthlott, W., Lauer, W., Placke, A. 1996. Global distribution of species diversity in vascular plants: towards a world map of phytodiversity. Erdkunde **50**: 317 ~ 327.

Boufford, D., Dijk, P. 1999. South-central China. In: Mettermeier, R.A., Myers, N., Mittermeier, C.G. (eds.) Hotspots: Earth's Biologically richest and most endangered terrestrial ecoregions, Cemex, Mexico City, Pp. 339 ~ 350

Buntaine, M.T., Mullen, R.B., Lassoie, J.P. 2006. Human use and conservation planning in alpine areas of northwestern Yunnan, China. Environment, Development and Sustainability, Published Online: 21 Feb. 2006. (http://www.springerlink.com/content/1573-2975/?k=buntaine)

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology **18**: 117 ~ 143.

Colwell, R.K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates.

CI. 2006. Conservation International's Biodiversity Hotspots. http://www.biodiversityhotspots.org/xp/Hotspots/china

Deng, M., Zhou, Z.K. 2004. Seed plant diversity on screes from northwest Yunnan. Acta Botanica Yunnanica **26**: 23 ~ 34.

Erschbamer, B., Virtanen, R., Nagy, L. 2003. The impacts of vertebrate grazers on vegetation in European high mountains. In: Nagy L, Grabherr G, Körner Ch, Thompson, D.B.A. (ed.) Alpine Biodiversity in Europe, Berlin, Springer-Verlag, Pp. 377 ~ 396.

Ferrier, S., Pressey, R.L., Barrett, T.W. 2000. A new predictor of the irreplaceability. of areas for achieving a conservation goal, its applicability to real-world planning, and a research agenda for further refinement. Biological Conservation **93**: 303 ~ 325.

Ge, X.J., Zhang, L.B., Yuan, Y.M., Hao, G., Chiang, T.Y. 2005. Strong genetic differentiation of the East-Himalayan *Megacodon stylophorus* (Gentianaceae) detected by inter-simple sequence repeats (ISSR). Biodiversity and Conservation **14**: 849 ~ 861.

Groves, C.R., Jensen, D.B., Valutis, L.L., Redford, K.H., Shaffer, M.L., Scott, J.M., Baumgartner, J.V., Higgins, J.V., Beck, M.W., Anderson, M.G. 2000. Planning for biodiversity conservation: Putting conservation science into practice. Bioscience **52**:499 ~ 512.

Hobohm, C. 2003. Characterization and ranking of biodiversity hotspots: centres of species richness and endemism. Biodiversity and Conservation **12**: 279 ~ 287.

Klotzi, F. 1997. Biodiversity and vegetation belts in tropical and subtropical mountains. In: Messerli, B., Ives, J.D. (eds.) Mountains of the World: a Global Priority, Parthenon Publishing Group, New York. Pp. 232 ~ 235.

Körner, Ch. 2003. Alpine Plant Life. Functional Plant Ecology of High Mountain ecosystems, Vol 2E, Springer-Verlag, Berlin-Heidelberg.

Kruskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika **29**:1 ~ 27.

Ma, C.L., Moseley, R.K., Chen, W.Y., Zhou, Z.K. 2007. Plant diversity and priority conservation areas of Northwestern Yunnan, China. Biodiversity and Conservation 16: 757-774.

Mather, P.M. 1976. Computational methods of multivariate analysis in physical geography. J. Wiley & Sons, London. 532 Pp.

McCune, B., Grace, J.B. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, Oregon, USA.

McCune, B., Mefford, M.J. 1999. PC-ORD. Multivariate Analysis of Ecological Data. MjM Software Design, Gleneden Beach, Oregon, USA.

McNab, W.H. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. Forest Science **35**: 91 ~ 104.

Meihe, G. 1997. Alpine vegetation types of the central Himalaya. In: Wiegolaski, F.E. (ed.) Ecosystems of the World 3. Polar and Alpine Tundra. Amsterdam. Pp 161 ~ 184.

Miller, D.J. 2000. Impacts of grazing in Himalayan and Tibetan

Plateau rangelands. Northern Plains Associates (http://www.mtnforum.org/)
Mittermeier, R., Meyers, N., Mittermeier, N., Gil, P., Ford, H. 1999. Hot spots: Earth's biologically richest and most endangered terrestrial ecoregions. Cemex, Conservation Int., Mexico City.
Mohamed-Saleem, M.A., Woldu, Z. 2002. Land use and biodiversity in the upland pastures in Ethiopia. In: Körner, Ch., Spehn, E.M. (eds.) Mountain Biodiversity: A Global Assessment, Boca Raton, Parthenon Publishing Group, Pp. 277 ~ 282.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature **403**: 853 ~ 858.
Olson, D.M., Dinerstein, E. 1998. The Global 200: a representation approach to conserving Earth's most biologically valuable ecoregions. Conservation Biology **12**:502 ~ 515.
OSU-SCAS. 2006. The Climate Source, Inc. Oregon State University. (http://www.climatesource.com/cn/fact_sheets/yunnanppt_xl.jpg)
Pressey, R.L., Johnson, I.R., Wilson, P.D. 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiversity and Conservation **3**: 242 ~ 262.
Salick, J., Anderson, J.D., Woo, J., Sherman, R.E., Cili, N., Yin, X.Z., Na, A., Sonam, Dorje. 2004. Tibetan ethnobotany and gradient analysis: Menri (Medicine Mountains), Eastern Himalayas. In The Millenium Ecosystem Assessment. Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Multi-Scale Assessments. Alexandria, Egypt. (http://www.millenniumassessment.org/en/about.Meetings. bridging.proceedings.aspx#2j)
TNC. 2006. The Nature Conservancy in China. (http://www.nature.org/wherewework/asiapacific/china/strategies)
Vane-Wright, R.I. 1996. Identifying priorities for the conservation of biodiversity: systematic biological criteria within a socio-political framework. In : Gaston, K.J. (ed.) Biodiversity: A Biology of Numbers and Difference, Blackwell, Oxford Pp. 309 ~ 344.
Xu, G., Kruse, C. 2003. Economic impact of tourism in China. In: Lew, A.A., Yu, L., Ap, J., Zhang, G.R. (eds.) Tourism in China, New York, Haworth Hospitality Press, Pp. 83 ~ 102.
Xu, J., Wilkes, A. 2003. Biodiversity impact analysis in northwest Yunnan, southwest China. Biodiversity and Conservation **13**: 959 ~ 983.
Xu, J., Fox, J., Lu, X., Podger, N., Leisz, S., Ai, X. 1999. Effects of Swidden Cultivation, State Policies, and Customary Institutions on Land Cover in a Hani Village, Yunnan, China. Mountain Research and Development **19**(2):123 ~ 132.
YGRPPT (Yunnan Great Rivers Project Planning Team). 2002. Yunnan Great Rivers Project: Northwestern Yunnan Ecoregional Conservation Assessment, Kunming, China, The Nature Conservancy.