Biodiversity and Conservation (2006) 15:1811–1828
DOI 10.1007/s10531-004-6681-6

Distribution and species diversity of plant communities along transect on the northeastern Tibetan Plateau

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Received 17 February 2004; accepted in revised form 10 November 2004

Key words: Distribution, Plant community, Species diversity, Tibetan Plateau, Transect

Abstract. The distribution and species diversity of plant communities along a 600 km transect through the northeastern Tibetan Plateau (32°42′–35°07′ N, 101°02′–97°38′ E) with altitudes from 3255 to 4460 m are described. The transect started from the Youyi Bridge of Banma through Dari, Maqin and Maduo to Zaling Lake. The data from 47 plots along the transect are summarized and analyzed. The mean annual temperature, the mean annual rainfall and the length of growing season decreases from 2.6 to −4.5 °C, from 767.2 to 240.1 mm, from 210 to 140 days, respectively, along the transect from the southeastern Banma to northwestern Zaling Lake. The number of vascular plant species recorded in 47 plots is 242 including 2 tree, 34 shrub, 206 herb species. Main vegetation types on the transect from southeast to northwest are: *Sabina convallium* forest, *Picea likiangensis* forest, *Pyracantha fortuneana* + *Spiraea alpina* shrub, *Hippophae neurocarpu* shrub, *Sibiraea angustata* + *Polygonum viviparum* shrub, *Stellera chamaejasme* herb meadow, *Potentilla fruticosa* + *Salix obscura* + *Carex* sp. Shrub, *Kobresia capillifolia* meadow, *P. froticosa* + *Kobresia humilis* shrub, *Caragana jubata* + *S. obscura* shrub, *Kobresia tibetica* meadow, *Kobresia pygmaea* meadow, *K. pygmaea* + *Stipa purpurea* steppe meadow, *Stipa purpurea* steppe. Plant richness and diversity index all showed a decreasing trend with increasing of elevation along transect from southeast to northwest. Detailed information on altitudinal ranges and distribution of the alpine vegetation, vascular flora and environments over the alpine zone at northeastern Tibetan Plateau provides baseline records relevant to future assessment of probable effects of global climate changes.

Abbreviations: DBH – Diameter at Breast Height; GPS – Global Positioning System; IV – Important Values; ELEV – Elevation; LAT – Latitude; LONG – Longitude; MAT – Mean annual temperature; MAR – Mean annual rainfall; LGS – Length of growing season; TGS – Temperature during growing season

Introduction

The Tibetan Plateau occupies an area of about 2,500,000 km^2, is the highest plateau in the world and often called 'the third pole'. The area influences Eurasian atmospheric circulation, the distribution of ecosystems and their structure, function, adaptation and evolutionary process (Chang 1983). In addition, the Tibetan Plateau is an area highly sensitive to global change. It could be considered as an indicative or forewarning area for global change, and therefore, an area of great significance for monitoring and research (Zhou and Zhan 1996).

Although alpine meadow and shrub cover 35% of the all plateau area, forest, grassland and desert ecosystem are also widely distributed (Zhao and Zhou 1999). Due to the rough conditions, the scarce investigations on the Tibet Plateau result in the poor knowledge of its biodiversity. Plant communities and distribution of biodiversity patterns along altitudes and latitudes in this area are still unclear. Investigation of spatial patterns of plant distribution is the basis for understanding mechanism how such patterns were formed (Fisher 1960; Bazzaz et al. 1975; Rohde 1992). Understanding spatial patterns is also the foundation for studies of species diversity which elucidate changes in species number and turnover, and how species diversity correlates with environmental factors (Nicholson and Monk 1974; Houssard et al. 1980; Rosenzweig 1995). In general, there are two main approaches to understand the ecological factors that impact on biodiversity, namely monitoring the effects of experimental manipulation on diversity within communities, and investigating natural gradients in diversity at large scales (Gould and Walker 1997; Wang et al. 2002).

Transect is a series of samples that are placed along environmental gradient. Transect sampling method is a effective way to collect non-continual gradient data and to study the structure, function and pattern variation of the communities (Gillison and Brewer 1985). On the Tibetan Plateau a given vegetation type usually occupies a very large area, which underlines both homogeneity of plant communities and of environments. However, four distinct vegetation types could be distinguished on the northeastern Tibetan Plateau: forest, alpine shrub, alpine meadow and alpine steppe. Transect sampling can reflect the main ecological types on the plateau and change law of the distribution pattern of individual plant species and of plant communities along a gradient. The ecotone, defined as the transitional area between two distinctive vegetation types, usually provides insight as to the affinity of species to certain communities (Rosenzweig 1995). Therefore, ecotones are selected as the large-scale survey targets.

Species diversity on the Tibetan Plateau have been studied in relatively few areas of the plateau considering its harsh condition. Sun and Zhu (2000) studied the plant species diversity in relation to altitude gradient in the *Kobresia pygmaea* meadow of Qilian mountain, Qinghai. The result showed plant richness peaked at the intermediate portion of the altitudinal gradient. Wang (2001) recorded the community structure and plant species diversity of the degraded ecosystems in the alpine *Kobersia* meadow of eastern Qinghai–Tibet Plateau and their correlation with human disturbance. Along degraded gradient, the plant richness and diversity decreased obviously. In the Gahai Salt Lake in the Qaidam Basin, Xu (2002) recorded plankton community diversity. Here, the salinity is an important limiting factor in determining the structure and species diversity of communities. However, we still have limited knowledge about patterns of plant species diversity of the natural vegetation of the Tibetan Plateau based on direct field data at large-scale and their possible correlation with environmental factors.

Alpine ecosystems tend to support many species at their physiological, and thus distributional, limits. With increasing concerns as to the possible effects of global climate change, particularly higher temperatures, alpine ecosystems and the species and communities they support, may serve as obvious signals of environmental change. Increasing temperatures are likely to result in changes in the distributional limits of species, making it important that we better understand the contemporary vegetation and species patterns of the alpine zone to provide the most reliable benchmark (Messerli and Ives 1997; Korner 1999).

The main objective of the present study was to describe and compare the variations (1) in the distribution and species diversity of alpine plant communities (2) in species composition along the transect on the northeastern Tibetan Plateau. With these results we wish to provide a basis for further experimental, mechanistic approaches to understanding causes of zonation and change over time.

Material and methods

Study area

The study plots were on the northeastern Tibetan Plateau (32°42′–35°07′ N, 101°02′–97°38′ E) with altitudes ranging from 3255 to 4460 m and most of them above 4000 m a.s.1. (Figure 1 and Table 1). The survey route comprises five geographical units: Banma county, Dari county, Maqin county, Maduo county and Zaling Lake. We chose a transect about 600 km in length and 20 km in width throughout coniferous forest, alpine shrub, alpine meadow and alpine steppe ecosystem from southeast to northwest. It started from the Youyi Bridge of Banma through Dari, Maqin and Maduo to Zaling Lake (Figure 1). The climate is characterized by long, cold winters and short, relative cool summers. The mean annual temperature decreases from 2.6 to −4.5 °C, and the mean annual rainfall decreases from 767.2 to 240.1 mm along the transect from the southeastern Banma to northwestern Zaling Lake.

Data collection

In the selected transect route, the ecotones between two vegetation types were easily identified. The vegetation types are sometimes mosaics but show a trend from forest, shrub, meadow to steppe types from southeast to northwest of the

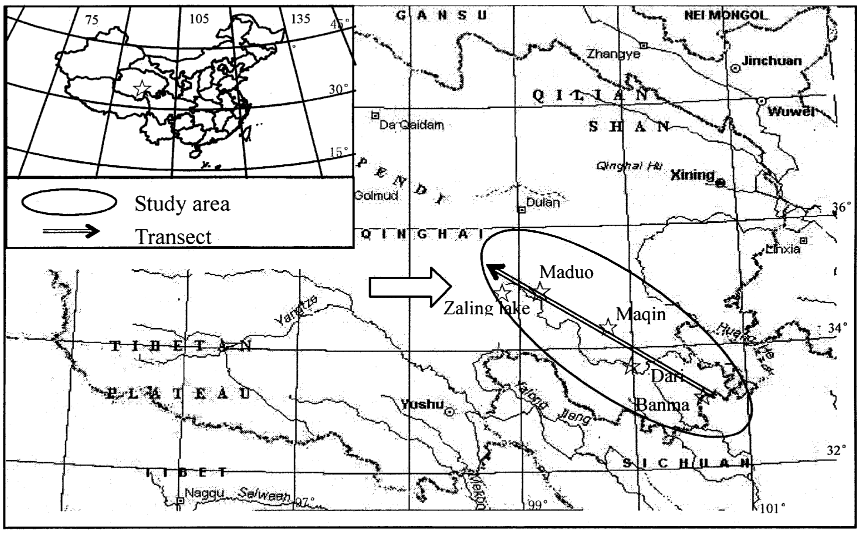

Figure 1. Location of the studied transect on the northeastern Tibetan Plateau.

Table 1. Site, geographical coordinates, altitudes and climate data of each investigated plot.

Plots	Sites	LAT	LONG	ELEV (m)	MAT (°C)	MAR (mm)	LGS[b] (day)	TGS (°C)
1	Youyi Bridge, Banma	32°42.04′	101°02.22′	3255	2.6	767.2	214	8.21
2	Banqian, Banma	32°43.08′	100°54.62′	3340	2.6	750.0	214	8.22
3	Banqian, Banma	32°43.08′	100°54.62′	3345	2.6	750.0	214	8.22
4	Banqian, Banma	32°44.01′	100°54.12′	3465	2.6	750.0	214	8.22
5	Banqian, Banma	32°44.01′	100°54.08′	3466	2.6	750.0	214	8.22
6	Banqian, Banma	32°42.50′	100°51.72′	3440	2.6	750.0	214	8.22
7	Banqian, Banma	32°42.55′	100°51.75′	3435	2.6	750.0	214	8.22
8	Banqian, Banma	32°45.52′	100°50.97′	3340	2.6	750.0	214	8.22
9	Yaertang, Banma	32°45.85′	100°49.87′	3360	2.7	713.5	216	8.24
10	Yaertang, Banma	32°46.16′	100°49.65′	3370	2.7	713.5	216	8.24
11	Yaertang, Banma	32°46.56′	100°47.18′	3420	2.7	713.5	216	8.24
12	Sailaitang, Banma[a]	32°52.13′	100°49.03′	3520	2.6	665.3	212	7.88
13	Sailaitang, Banma[a]	32°54.43′	100°42.46′	3590	2.6	665.3	212	7.88
14	Sailaitang, Banma[a]	32°59.56′	100°41.99′	3580	2.6	665.3	212	7.88
15	Sailaitang, Banma[a]	32°59.78′	100°41.97′	3590	2.6	665.3	212	7.88
16	Duogongma, Banma	33°06.50′	100°34.90′	3700	1.2	696.2	199	7.29
17	Duogongma, Banma	33°10.20′	100°29.28′	3810	1.2	696.2	199	7.29
18	Duogongma, Banma	33°10.21′	100°31.47′	3810	1.2	696.2	199	7.29
19	Deang,Dari	33°16.71′	100°23.80′	4310	-2.8	600.0	160	5.37
20	Deang,Dari	33°23.21′	100°13.10′	4240	-2.8	600.0	160	5.37
21	Wosai, Dari	33°27.79′	99°59.28′	4085	-2.2	569.0	170	5.75
22	Jiemai, Dari[a]	33°46.55′	99°27.79′	4150	-1.2	569.0	170	6.36
23	Dangxiang, Maqin	33°54.73′	99°47.17′	4250	-2.7	530.0	160	5.37
24	Dangxiang, Maqin	33°54.70′	99°47.10′	4248	-2.7	530.0	160	5.37

Table 1. Continued.

25	Dangxiang, Maqin	33°55.76′	99°44.49′	4350	-2.7	530.0	160	5.37
26	Dangluo, Maqin	33°58.24′	99°28.28′	4070	-2.5	565.9	–	–
27	Dangluo, Maqin	34°03.78′	99°23.59′	4180	-2.5	565.9	–	–
28	Shiyu, Maqin	34°08.09′	99°19.50′	4350	-3.4	500.0	–	–
29	Youyun, Maqin[a]	34°21.37′	99°11.80′	4221	-3.9	441.9	143	5.35
30	Youyun, Maqin[a]	34°21.38′	99°11.80′	4221	-3.9	441.9	143	5.35
31	Youyun, Maqin[a]	34°21.39′	99°11.82′	4220	-3.9	441.9	143	5.35
32	Tanggema, Maduo	34°39.86′	99°07.04′	4460	-4.2	312.0	141	4.43
33	Yeniugou, Maduo	34°41.36′	98°04.61′	4304	-4.2	235.0	141	4.95
34	Machali, Maduo[a]	34°43.54′	98°06.10′	4205	-4.1	326.3	141	5.28
35	Machali, Maduo[a]	34°43.55′	98°06.11′	4205	-4.1	326.3	141	5.28
36	Machali, Maduo[a]	34°43.56′	98°06.12′	4205	-4.1	326.3	141	5.28
37	Machali, Maduo[a]	34°43.57′	98°06.13′	4205	-4.1	326.3	141	5.28
38	Machali, Maduo[a]	34°43.71′	98°05.94′	4210	-4.1	326.3	141	5.28
39	Machali, Maduo[a]	34°43.78′	98°06.60′	4225	-4.1	326.3	141	5.28
40	Machali, Maduo[a]	34°46.58′	98°07.27′	4340	-4.1	326.3	141	5.28
41	Machali, Maduo[a]	34°50.83′	98°07.85′	4220	-4.1	326.3	141	5.28
42	Machali, Maduo[a]	34°52.11′	98°08.85′	4222	-4.1	326.3	141	5.28
43	Machali, Maduo[a]	34°53.29′	98°10.26′	4205	-4.1	326.3	141	5.28
44	Machali, Maduo[a]	34°51.23′	98°17.37′	4205	-4.1	326.3	141	5.28
45	Machali, Maduo[a]	34°57.44′	98°07.42′	4210	-4.1	326.3	141	5.28
46	Zhaling Lake[a]	35°01.81′	97°38.95′	4230	-4.5	240.1	141	4.74
47	Zhaling Lake[a]	35°06.79′	97°47.08′	4240	-4.5	240.1	141	4.74

MAT – Mean annual temperature; MAR – Mean annual rainfall; LGS – Length of growing season; TGS – Temperature during growing season.

[a] There are national meteorological stations; Others are short-term meteorological observation sites.

[b] Length of growing season: the durable days daily mean temperature exceeded 0 °C steadily.

transect. The total 47 permanent plots were selected as representative of the ecotones along transect and sampled, 9 for forest plots, 11 for shrubs plots and 27 for meadow and steppe plots. In each plot, at least two quadrates were sampled, resulting in a total of 111 quadrates. The quadrate sizes were: 10×10 m^2 for forest type, 5×5 m^2 for the shrub type, and 1×1 m^2 for steppe and meadow types. The vegetation was divided by tree, shrub and herb layers. In each plot, all vascular species were identified, and percent cover and height for each recorded vascular plant species and diameter at breast height (DBH) of trees were measured. In addition, longitude, latitude and elevation each plot were measured by GPS. The collected climate variables included mean annual temperature, mean annual rainfall, length of growing season and mean temperature during growing season. The survey route comprises five geographical units, and there is a meteorological station within each unit. In order to obtain climatic data of plots more accurate, we also adopted climatic data of short-term meteorological observation sites along the transect. The detail information and explanation about climate data was listed below in Table 1. These climate data were obtained from the sources and programme of livestock husbandry at programming office of Banma, Dari, Maqin and Maduo County.

Data analysis

All quadrates within each plot were pooled. Species important values (IV = (relative height + relative cover)/2) for shrub layer and herb layer and (IV = (relative height + relative cover + relative DBH)/3) for tree layer were calculated. Two indices were chosen for estimation of diversity according to Pielou (1969): (1) Plant richness S represented by number of species recorded in each plot. (2) Shannon-Wiener's index of diversity $H' = -\sum pi \log_2 pi$, where $pi =$ the important value of i species at each plot.

Regression analyses were run on the altitudinal and horizontal distribution of plant richness and diversity index based on the plot data. All linear regressions were performed in SPSS ll.0.

Results

Characteristics of the plots

Geographical coordinates, altitudes and climate data of each investigated plot were presented in Table 1. In general, the elevation tended to increase along the transect from southeast to northwest, especially in the initial portion of the transect. The mean annual temperature decreases from 2.6 to −4.5 °C, and the mean annual rainfall decreases from 767.2 to 240.1 mm along the transect from the southeastern Banma to northwestern Zaling Lake. The length of growing season in the beginning part of the transect was about 210 days and that in the end part of the transect was only 140 days. The difference between them was about 70 days. The mean temperature during growing season decreases from 8.2 to 4.7 °C from the southeastern Banma to northwestern Zaling Lake.

Species components and distribution

The number of vascular plant species recorded in all plots was 242 including 2 tree, 34 shrub, 206 herb species, and ranging from 4 to 43 species in individual plots (Table 2). Among the 242 vascular plant species, 87 were sporadic components and only 7 were frequent components (frequency of occurrence > 33%) in the surveyed plots (e.g. *Poa psilolepis, Festuca ovina, Leontopodium nanum, Taraxacum lugubre, Ajania argyi, Elymus nutans, Koeleria cristata)*. Other species only occurred on several specified plots.

Along the transect from southeast to northwest these communities and their brief characteristics are as follows: The beginning part of the transect, from 3255 to 3466 m, was dominated by the pure forest of *Sabina convallium* on the sunny slope and of *Picea likiangensis* on the shady slope. *Picea likiangensis* forests are characterized by a well-developed, dense canopy in gentle slope and by a relatively open canopy in abrupt slope. The common understory shrubs in

Table 2. Vascular plant species and their percent cover in 47 plots along the transect.

Plots	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Trees																																															
Sabina convallium	75	40	50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Picea likiangensis	–	–	20	70	75	50	20	30	–	–	78	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Shrubs																																															
Cotoneaster adpressus	10	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elsholtzia staunni	2	2	10	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Clematis tangutica	0.5	5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Artemisia gmelinii	15	3	–	–	–	–	–	–	30	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spiraea mongolica	2	15	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lonicera hispida	–	20	5	–	2	0.5	2	1	–	–	2	1	0.5	1	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Derberis diaphana	0.5	1	1	–	–	2	–	–	–	5		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potentilla glabra	–	–	2	1	–	–	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Caragana chinghaiensis	–	–	–	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Berberis dubia	–	–	–	5	–	–	–	5	5	5	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ribes meyeri	–	–	–	3	2	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ribes stenocarpum	–	5	5	–	30	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spiraea rosthornii	–	–	–	–	5	–	2	3	–	–	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lonicera rupicola	–	–	–	–	15	–	5	10	2	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Salix atopantha	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rosa sp.	–	–	–	–	3	5	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ribes glaciale	–	–	–	–	–	20	3	–	–	–	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rubus lutescens	–	–	–	–	–	10	50	–	–	–	–	–	–	–	–		–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sorbus hypehensis	–	–	–	–	–	8	10		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–
Caragana tangutica	–	–	–	–	–	–	–	6	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–
Potentilla fruticosa	–	–	–	–	–	–	–	1	–	–	–	3	–	30	–	25	–	–	25	–	–	5	15	–	10	–	–	4.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sibiraea angustata	–	–	–	–	–	–	–	–	–	–	10	50	45	50	–	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hippophae neurocarpus	–	–	–	–	–	–	–	–	10	40	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pyracantha fortuneana	–	–	–	–	–	–	–	–	30	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cotuneaster acutifolius	–	–	–	–	–	–	–	–	2	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Caragana microphylla	–	–	–	–	–	–	–	–	–	–	–	10	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Continued

Plots	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Spiraea alpina	–	–	–	–	–	–	–	–	30	–	–	–	1	1	–	–	–	–	0.5	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Salix obscura	–	–	–	–	–	–	–	–	–	–	–	–	15	5	–	20	–	–	–	–	–	10	45	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Salix juparica	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Caragana jubata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Herbs																																															
Stellaria graminea	2.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oryzopsis tibetica	10	7.5	23	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Artemisia tanacetifolla	23	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leontopodium leontopodioides	12	0.5	–	–	–	–	–	–	15	–	–	6.5	–	–	2.5	1	2	5	2.5	–	–	0.5	–	3	–	3.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Thalictrum foetidum	8.3	6.5	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Delphinium grandiflorum	0.7	0.5	0.5	–	–	–	–	–	2	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pedicularis cristatella	1	0.5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anaphalis lactea	0.7	0.5	0.5	–	–	–	–	1	–	3	–	0.5	–	0.5	0.5	–	0.5	1.5	2.5	–	0.5	–	–	–	–	–	–	0.5	–	–	–	4.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Artemisia argyi	3	2.5	15	–	–	–	–	0.5	5	1	–	1	–	–	–	–	–	13	–	–	–	0.5	–	–	–	0.5	–	0.5	–	4	0.5	–	–	13	–	2	–	5	1.5	–	–	–	–	–	5.5	–	–
Galium verum	3	1	1	–	–	–	–	–	6	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potentilla griffithii	3.3	–	0.5	0.5	–	–	–	–	1	1	1	13	2	–	1.5	–	–	–	1.5	–	–	2.5	–	–	4.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veronica ciliata	0.3	–	0.5	–	–	–	–	–	–	–	0.5	–	–	0.5	0.5	–	–	1	–	1	–	–	–	–	–	1	–	0.5	–	0.5	–	–	0.3	–	–	–	–	–	–	–	0.5	–	–	–	–	–	–
Poa psilolepis	3.3	1	0.5	–	–	–	–	1	–	–	1.5	–	–	–	2	–	–	1	–	–	1	–	–	7	–	4	–	0.5	–	0.5	–	0.5	1.8	–	8	–	–	–	–	1	8.5	3	–	–	1.5	2.5	3
Roegneria breviglumis	0.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	1	–	1	–	–	–	–	–
Vicia angustifolia	–	0.5	0.5	–	–	–	–	–	2	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Primula palmata	3.3	6	7.5	–	–	–	0.5	4	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ixeris denticulate	–	–	0.5	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Thalictrum aquilegifolium	–	–	–	–	0.3	0.7	2.5	0.5	2	15	0.5	–	–	–	8	–	–	–	2.5	–	–	–	–	–	0.5	1.5	–	0.5	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Carpesium lipskyi	0.5	5	–	2.5	3.7	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Themeda triandra	–	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Festuca ovina	–	1	–	–	–	–	–	–	1	–	3.5	–	10	5	2.5	–	–	–	7.5	4	–	20	3.5	10	–	12	–	2.5	9	–	2	1	–	–	–	1	40	–	–	–	–	2.5	5	–	–	–	–
Scutellaria rehderiana	–	0.5	–	–	–	–	–	15	1	–	0.5	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dianthus superbus	–	0.5	–	–	–	–	–	–	1	1	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Salvia przewalskii	–	0.5	–	–	–	0.7	–	0.5	4	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aster souliei	–	–1	–	–	–	–	0.5	5	10	–	4.5	1	–	–	–	–	–	–	9	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Deyeuxia longiflora	–	–	2.5	–	1.3	0.3	2	–	2	–	–	–	–	–	–	–	0.5	–	–	–	5	0.5	–	–	–	3	0.5	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Impatiens apsotis	–	–	1	0.5	0.3	17	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polygonum viviparum	–	–	–	4	3	–	–	13	–	–	5.2	40	40	10	–	7.5	–	–	–	–	–	–	–	5	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elymus nutans	–	–	–	5.5	1	–	–	–	–	1	–	0.5	4	–	0.5	–	1	1	–	1	–	10	0.5	–	–	–	–	0.5	1.5	–	–	0.5	–	0.5	–	30	–	–	–	–	0.5	–	–	–	–	–	–
Ptilagrostis concena	–	–	–	1	1.7	–	–	0.3	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Carex lanctolata	–	–	–	40	50	7.3	20	–	–	–	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polygonatum verticillatum	–	–	–	1	–	–	0.5	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Corydalis straminea	–	–	–	0.5	–	1	1	–	1	–	–	0.5	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fragaria orientalis	–	–	–	–	0.3	5.3	–	8	–	–	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Viola yedoensis	–	–	–	–	2.3	0.7	–	–	–	–	1	–	–	–	–	–	–	–	–	–	0.5	–	–	1.5	–	0.5	0.5	–	–	–	–	0.5	0.1	–	–	–	–	–	–	–	0.5	–	–	–	–	–	–
Impatien macrophylla	–	–	–	–	–	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Urtica tragularis	–	–	–	–	–	1	0.3	1.5	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bromus remotiflorus	–	–	–	–	–	2	–	–	–	–	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polygonum alatum	–	–	–	–	–	10	–	–	–	–	–	5	1	–	15	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Swertia mussotii	–	–	–	–	–	0.3	–	1	2	–	0.5	–	–	–	–	–	–	0.5	–	–	1	–	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Comastoma pulmonarium	–	–	–	–	–	0.3	–	2.5	–	–	–	–	–	–	–	–	–	–	1	–	–	–	0.5	1	–	2.5	2	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pedicularis verticillata	–	–	–	–	–	–	0.3	–	–	10	–	0.5	1	0.5	–	0.5	–	–	0.5	–	–	–	–	–	–	–	–	1	–	0.5	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leontopodium calocephalum	–	–	–	–	–	–	–	1	–	–	0.5	–	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Adenophora elata	–	–	–	–	–	–	–	0.5	–	5	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Geranium sibiricum	–	–	–	–	–	–	–	0.5	–	–	1.5	2.5	10	15	–	–	5	0.5	–	–	–	7.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Koeleria cristata	–	–	–	–	–	–	–	–	–	–	0.5	2.5	3	0.5	1	–	1	–	0.5	–	1	0.5	0.5	–	–	1.5	1	1.5	–	0.5	–	–	–	–	–	8	–	–	–	–	0.5	–	–	–	–	–	2
Poa crymophila	–	–	–	–	–	–	–	–	8	5	–	–	5	8	–	–	–	–	0.5	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hedysurum multijugum	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Clematis intricata	–	–	–	–	–	–	–	–	2	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Senecio diversipinnum	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Taraxacum lugubre	–	–	–	–	–	–	–	–	1	–	–	0.5	1	0.5	3	–	–	2.5	0.5	1	1	–	–	0.5	3.5	5	–	1	1	–	–	–	0.5	–	–	–	–	–	–	0.5	1.5	–	0.5	–	–	–	–
Bupleurum longicaule	–	–	–	–	–	–	–	–	1	1	–	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Stellera chamaejasme	–	–	–	–	–	–	–	–	–	1	–	3.5	–	–	33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gueldenstaedtia diversiffolia	–	–	–	–	–	–	–	–	–	1	–	–	–	–	2.5	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anemone obtusiloba	–	–	–	–	–	–	–	–	–	1	–	6	1	–	0.5	–	–	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trigonella ruthenica	–	–	–	–	–	–	–	–	–	1	–	3	–	–	7.5	–	–	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Halenia elliptica	–	–	–	–	–	–	–	–	–	–	–	5	1	1.5	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kobresia humilis	–	–	–	–	–	–	–	–	–	–	–	2.5	–	–	6.5	–	–	–	35	–	2.5	–	0.5	–	–	3	–	18	23	–	–	43	0.8	–	–	5	–	–	–	4	6.5	–	–	–	–	–	–
Lancea tibetica	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	0.5	–	–	–	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Continued

Plots	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Euphorbia altotibetica	–	–	–	–	–	–	–	–	–	–	–	0.5	–	0.5	–	–	2	–	1.5	6.5	–	1	0.5	–	–	–	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Agrostis hugoniana	–	–	–	–	–	–	–	–	–	–	–	6.5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Saussurea katochaete	–	–	–	–	–	–	–	–	–	–	–	0.5	–	0.5	–	–	–	–	5.5	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gentiana squarrosa	–	–	–	–	–	–	–	–	–	–	–	1	4	–	0.5	–	1	5.5	1	–	1.5	–	–	0.5	1.5	–	1.5	–	–	–	3	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Euphrasia pectinata	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	–	2.5	–	0.5	–	–	1.5	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Saussurea superb	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1.5	–	–	–	–	–	1.5	30	–	15	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	–
Polygonum sphaerostachyum	–	–	–	–	–	–	–	–	–	–	–	–	1	0.5	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anemone trullifolia var. linerria	–	–	–	–	–	–	–	–	–	–	–	–	3	2.5	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleurospermum pulszkyi	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	0.5	–	–	3.5	11	–	–	–	–	0.5	–	–	0.5	1.5	–	3.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cremanthodium plantaginum	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	3	–	–	–	–	–	–	–	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gentiana straminea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.5	–	0.5	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	0.5	–	–	–	–	–	–
Aster alpinum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	5.5	–	–	3	–	–	–	–	3.5	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Saussurea woodiana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	2.5	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potentilla saundersiana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.5	–	4.5	4.5	–	12	1.5	–	–	3	–	18	–	15	–	–	–	–	0.3	–	–	–	–	–	–	8	6.5	10	–	–	–	–	–
Pedicularis kansuensis	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	1.5	–	–	–	–	–	0.5	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Saxifraga montana	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	0.5	–	–	1	–	–	–	0.5	–	–	–	–	–	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pedicularis longiflora	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1.5	1.5	–	–	–	14	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptilagrostis concinna	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	5	–	–	–	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lamiophlomis rotata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	3.5	–	–	–	–	–	4.5	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rheum pumilum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	4.5	–	–	2.5	–	–	7.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kobresia capillifolia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	35	–	–	–	7.5	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Saussurea stella	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.5	–	–	2	–	–	–	–	9	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gentiana farreri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	1	–	–	–	–	–	3.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Leontopodium nanum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.5	–	5	0.5	–	–	–	–	–	0.5	2.5	7.5	1	13	1.5	4.5	1	–	6	–	1	1	0.5	14	–	–	9	–	24	3.5
Kobresia pygmaea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.5	3.5	75	1	–	–	65	43	50	–	73	20	–	60	35	60	–	–	–	–	–	–	68	50	–	–	–	–	–	–
Festuca rubra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.5	–	–	–	5	–	13	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Androsace integra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	0.5	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Carex atrofusca	–	–	–	–	–	–	–	–	4	–	–	–	4	5	0.5	23	–	–	13	1.5	7	3.5	19	–	1.5	–	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Astragalus polycladus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	9	10	–	–	–	–	–	–	10	25	0.5	–	–	–	1	1
Potentilla bifurca	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	4.5	1	–	–	14	–	–	2	1	–

Ranunculas brotherusii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	–
Cremanthodium lineare	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kobresia tibetica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	–	–	–	–	–	65	0.5	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–
Trollius farreri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	–	–	–	–	1.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Allium cyaneum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parnassia lutea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–
Ligularia virgaurea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lagotis brachystachya	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.5	–	–	–	0.5	2	0.5	7.5	1	–	15	–	–	–	2	1	–	–	–	–	–	–	–	–
Lonicera tibetica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2.5	–	–	–	–	–	–	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ptilagrostis dichotoma	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	5	1	0.5	4.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Kobresia prattii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Androsace zambalensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.5	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Arenaria pulvinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	0.5	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	15
Saussurea eopygmaea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	45	–	–	–	–	–	–	–	–	20	–	7.5	–	–	–	0.5	–	–	–
Iris collettii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	0.5	–	–	–	–	–	0.5	–	–	–	–	–	0.5	–	–	–
Cheiranthus roseus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	0.5	–	–	–	–	–	–	–	–	2.5	–	–	–	–	–	–	–	–
Stipa purpurea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	38	–	–	3	–	–	–	–	–	38	6	5.5	30	–	40	23	33	9
Thalictrum alpinum var. elatum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	0.8	–	–	–	–	–	1	–	–	–	–	–	–	–
Polygonum sibiricum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	8	3	6.5	1	0.5	–	–	–	0.5	–	–	–	–
Draba dasyastra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	0.5	1	–	–	–	–	–	–	–	–
Pedicularis alaschanica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	–	–	–	1.5	–	–	–	–	–	–	–	–
Saussurea arenaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	0.5	–	–	–	–	–	–
Glaux maritime	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	70	–	10	–	–	–	–	–	18	–	–	–	–
Carex moorcroftii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15	–	–	2	0.5	–	–	–	–	–	1	–
Androsace tapete	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11	2	–	–	–	13	–	–	–	–	–	–	–	–	–
Oxytripis deflexa	–	–	–	–	–	–	–	–	–	–	–	2.5	–	–	12	–	–	–	–	–	1.5	5	4	1	–	23	–	7.5	10	–	16	–	–	–	–	–	–	–	–	2	13	–	–	–	–	–	–
Carex stenophylla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.5	15	–	–	–	5	–
Puccinellia roborovskyi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	25	9	–	–	–
Sibbaldia pentophylla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20	–	–	–	–	–
Ajania khartensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	18
Heteropappus altaicus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.5	–	–	–	1	6	–	–	–	–	–	1.5	–	1
Pteridophyta																																															
Adiantim fimbriatum	1.7	–	2.5	18	7.7	–	30	1	–	–	0.5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Drynaria sinica	–	34	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Continued

Plots	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
Dryopteris barbigera	–	–	8	–	–	–	40	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total species number incl. sporadic species	26	31	31	23	25	30	22	33	43	34	25	37	30	30	29	12	17	24	32	15	30	29	27	17	20	23	17	27	14	16	13	21	14	12	6	9	4	11	14	14	16	8	9	8	7	10	9

Sporadic species(species only occurred in one or two plot and percent cover < 5% in the plot was called as sporadic species, and expressed as No. of the plot: percent cover): **Shrubs**: *Lonicera microphylla* 4:2; *Tamarix chinensis* 8:5; *Betula platyphylla* 8:5; *Polygonum aubertii* 9:5; **Herbs**: *Carex crebra* 1:5; *Astragalus satoi* 1:4; *Heracleum candicans* 2:2; 3:0.5; *Aster tongolensis* 2:1; *Melilotoides archiducis* 2:2.5; *Dracocephalum tanguticum* 2:0.5; *Lathyrus quinguenrvius* 2:2; 3:5; *Allium chrysanthum* 3:0.5; 10:1; *Leibinitzia nepalensis* 3:0.5; *Saxifraga egregia* 4:3; *Rhodiola kirilovii* 4:0.; 5:1.7; *Cacalia deltophylla* 4:1.5; *Caltha scaposa* 4:0.5; 21:4.5; *Listera puberula* 4:0.5; 6:0.7; *Anemone imbricata* 4:0.5; 15:0.5; *Cimicifuga foetida* 5:1.7; 7:0.3; *Circaea alpina* 5:1; *Pedicularis rudis* 5:0.3; 8:0.5; *Chamaenerion angustifolium* 5:5; 13:1; *Chenopodium hybridum* 6:0.3; *Galium aparine* 6:0.7; 7:2; *Erodium stephanianum* 6:5; *Circaeaster agrestis* 6:1.7; *Stellaria nmbellata* 6:0.3; *Ranuculus tanguticus* 6:0.3; 43:5; *Epilobiium royleanum* 7:0.5; *Valeriana minutoflora* 7:0.3; *Rubia cordifolia* 8:0.5; *Herminium monorchis* 8:0.5; *Ligularia przewalskii* 22:1; *Cuscuta chinensis* 9:1; *Serratula strangulata* 9:2; *Chenopodium foetidum* 9:2; *Ajania tenuifolia* 9:1; 13:1; *Polygonum hookeri* 9:2; *Ranunculus membranaces* 9:1; *Fagopyrum tataricum* 9:2; *Rumex acetosa* 9:1; *Artemisia* sp. 10:1; 12:0.5; *Calamagrostis epigejos* 10:1; *Senecio integrifolius* 12:0.5; *Equisetum arvense* 13:1; 14:0.5; *Patrinia heterophylla* 13:1; 14:1; *Anemone rivularis* 14:3; *Gentianopsis paludosa* 14:1; 18:1; *Deschampsia caespitosa* 14:0.5; 27:2; *Artemisia subdigitata* 15:2.5; *Halerpestes tricuspis* 18:5; *Coluria longifolia* 19:1; 27:1.5; *Saussurea salicifolia* 19:4.5; 25:1; *Stipa aliena* 19:0.5; 25:2; *Saussurea kokonorensis* 19:4.5; 20:0.5; *Saxifraga melanocentra* 21:0.5; *Ranunculus pulchellus* 21:2; *Chamaecium paradoxum* 21:5; *Potentilla anserine* 21:1.5; 35:1; *Cardamine tangutorum* 21:0.5; 22:0.5; *Blysmus sinocompressus* 21:2.5; 36:2; *Pedicularis cheilanthifolia* 22:1; *Notopterygium incisum* 21:0.5; 22:2; *Iris goniocarpa* 22:0.5; *Polygonum tenuifolium* 23:1; *Allium herderianum* 23:1; *Helictotrichon tibeticum* 23:1; *Triglochin martimum* 27:1; 43:2.5; *Cremantbodium brunneopilosum* 27:2; *Gentiana pseudosguarrosa* 28:5; *Carex enervis* 28:3; 46:0.5; *Astragalus mattam* 28:2.5; *Meconopsis horridula* 28:0.5; *Pornatosace filicula* 30:2; 31:1; *Littledalea przewalskyi* 32:2.5; *Saussurea thoroldii* 33:3; *Corydalis dasysptera* 34:1.5; *Artemisia desertorum* 38:5; 39:2; *poa tibetico* 44:0.5; *Thermopsis lanceolata* 44:1; *Oxytropis maduoensis* 44:0.3; 45:1.5; *Oxytropis densa* 26:5; 45:1; *Ephedra monosperma* 46:0.5; *Oxytropis falcate* 47:1; *Pteridophyta: Polystichum sinense* 4:0.5; *Cystopteria fragilis* 5:3; 8:2.5

these communities included *Ribes glaciale, Lonicera rupicola, Caragana chinghaiensis, Rubus lutescens*, and herbs *Carex duriuscula, Adiantim fimbriatum, Polygonum viviparum, Impatiens apsotis, Dryopteris barbigera. Sabina convallium* forest usually occupied the steep, sunny rocky slope and was dominated by *Spiraea mongolica, Lonicera hispida, Cotoneaster adpressus, Elsholtzia staunni, Artemisia gmelinii* in shrub layer and *Oryzopsis tibetica, Thalictrum foetidum, Artemisia argyi, Primula palmate* in herb layer. *Sabina convallium* and *Picea likiangensis* forests in the transect are the extended part of southwest subtropical forest of China to Tibetan Plateau and also upper limit of coniferous forest. Shrub plots from 3300 to 3400 m were dominated by *Hippophae neurocarpus, Pyracantha fortuneana* and accompanied by shrub *A. gmelinii, Cotuneaster acutifolius* and *Berberis dubia*, and there was no significant dominant herb species. Relatively high species richness as compared to other plots (Table 2) may be attributable to sufficient light and moderate climate condition. *Sibiraea angustata* shrubs between 3500 and 3600 m represented the transition zone from cold-temperate coniferous forest to alpine shrubs. Common species in these communities included shrubs *Caragana microphylla, Potentilla fruticosa, Salix obscura* and herbs *P. viviparum, Geranium sibiricum, Poa crymophila. Potentilla fruticosa* shrubs are distributed at relatively wide range on the Tibetan Plateau. These shrublands in the transect ranged from 3340 to 4350 m, occupying the shady and semi-shady slopes. *P. fruticosa* can coexist with *S. angustata*, *S. obscura, P. viviparum* in the communities with elevation below 3700 m, and coexist with meadow plants such as *Kobresia humilis, Kobresia pygmaea, Carex atrofusca and Festuca rubra* in the communities with elevation above 4000 m. Particularly, it is only shrub in the plots of elevation above 4300 m. In addition, alpine shrubs were mosaic with herb meadow (plot 15, 17) or *Kobresia capillifolia* meadow (plot 18) at elevation below 4000 m while alpine shrubs, especially *P. fruticosa* shrubs, were mosaics with *K. pygmaea* or *Kobresia tibetica* meadows (e.g. plot 20, 21, 24, 26, 27) at elevation above 4000 m.

Potentilla fruticosa is generalist species on the Tibetan Plateau, and occurred on 9 plots (e.g. plot 8, 12, 14, 16, 22, 23, 19, 25, 28) ranging from 3340 to 4350 m in the transect (Table 3). Along the transect, percent cover and height of *P. fruticosa* all peaked at ca. 3580 m then declined below or upper this elevation. For example its mean height was 20 cm in the forest plot of elevation

Table 3. The distribution gradient and basic characteristics of *Potentilla fruticosa* in different plots.

Plots	8	12	14	16	22	23	19	25	28
Altitude (m)	3340	3520	3580	3700	4150	4250	4310	4350	4350
Cover (%)	1	3	30	25	5	15	25	10	4.5
Height (cm)	20	30	40	25	20	15	7	5	3
imp. Value (%)	2.5	7.8	21.6	22.4	10.8	26	60	100	100

3340 m, 31.7 cm in the plots of elevation 3500–3700 m and 10 cm in plots with elevation above 4000 m. This may be attributed to dense canopy in the forest plot and harsh climate condition in the plots with elevation above 4000 m. This suggested that it can grow better at the relatively suitable condition even though its distribution was wide.

Along transect toward northwest, alpine meadow completely substituted for alpine shrub in the end (the vegetation completely changed into alpine meadows). Usually *K. pygmaea* meadow, occupying relatively arid area, was predominated by *K. pygmaea* and accompanied by *Oxytripis deflexa, Leontopodium nanum, Astragalus polycladus, Potentilla saundersiana, Saussurea superb, K. humilis*. *K. tibetica* meadow was confined to specific habitats such as those with seasonal surface water flow, and predominated by *K. tibetica*, accompanied by *Trollius farreri, Saussurea stella*, *C. atrofusca, Cremanthodium* sp. Along the northwestward transect, plot 39, 40, 41 located in the transition zone from alpine meadow to alpine steppe, were characterized by the coexistence of meadow plants such as *K. pygmaea, K. humilis, Carex*sp. and steppe plants such as *Stipa purpurea, Saussurea arenaria*. The ending portion of the transect was dominated by alpine steppe. *S. purpurea* was dominant species in these communities. Alpine steppes are also characterized by low total vegetation cover, low and small plant and few species number in the plots. This may be attributable to extreme climate and strong radiation on this region.

Plant richness (species number) and diversity index (Shannon index) in relation to altitude

Using the sample plot data, a linear regression (SLR) of plant richness against altitude was significant with the regression accounting for 43.7% of the variation. So did diversity index, and with the regression accounting for 57.4% of the variation (Figure 2). Linear regression equations were respectively:

$$SPECIES\ RICHNESS = 86.431 - 0.0167 ELEV \quad R^2 = 0.437 \quad p < 0.001$$

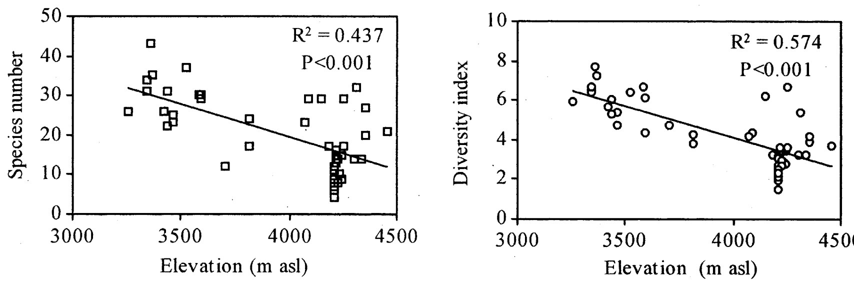

Figure 2. The species number and diversity index trend with altitude, based on the 47 plots along transect. Linear regression line is showed.

$$DIVERSITY\ INDEX = 16.787 - 0.0032ELEV \quad R^2 = 0.574 \quad p < 0.001$$

Plant richness and diversity index all decreased with increasing of elevation. There is a mean reduction of 1.67 species for each 100 m increase in altitude, close to the value of an average attrition of 1.8 species per 100 m increase in altitude given by Mark et al. (2000) for Mount Armstrong in the Southern Alps. An average reduction in diversity index is 0.32 for each 100-m increase in altitude.

Plant richness and diversity index in relation to longitude–latitude gradient

Plant richness index showed a decreasing trend along transect from southeast to northwest (Figure 3), and species diversity has same trend (figure omitted). A linear regression of plant richness, diversity index against longitudinal–latitudinal gradient were significant respectively. Linear regression (MLR) equations were respectively:

$$SPECIES\ RICHNESS = -205.1 - 4.14LAT + 3.67LONG \quad R^2 = 0.665 \quad p < 0.001$$

$$DIVERSITY\ INDEX = 58.16 - 1.554LAT - 0.0129LONG \quad R^2 = 0.710 \quad p < 0.001$$

So, plant richness and diversity index all drop with increase of latitude and decrease of longitude (western location).

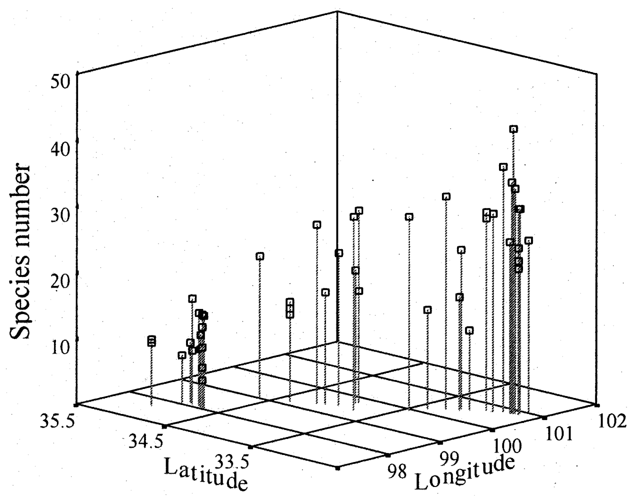

Figure 3. The species number trend with latitude–longitude gradient, based on the 47 plots along transect.

Discussion

The Banma region where is the initial point of the transect is gorge geomorphy due to gully of Lancang river and yangzi river and there are many transverse mountains from southeast to northwest. So, it forms a passage for southwest warm-air mass to the plateau. But the effect of monsoon on climate weakens gradually from southeast to northwest (Zhou et al. 1987). So, the precipitation decreases gradually along the transect and temperature drops gradually with elevation increase. The hydro–thermo is synchronous at whole transect and drop gradually from southeast to northwest.

Species diversity can be used as indicators of ecological gradients and the environmental quality of an ecosystem (Alard et a1. 1994; Alard and Poudevigne 2000). If so, the initial portion on the transect where is an optimal combination of environmental resources may be peaked at higher species diversity. This theory was proved at the present paper. Various studies show that elevation provides a complex gradient where ecological factors vary in different spatial scale, and plants respond to different combinations of ecological factors (Barrera et al. 2000). In the present paper, the fluctuations demonstrated by species diversity and plant richness along the altitudinal gradient, at some extent, might be a response to the complexity of vegetation-environment relation.

Our analysis revealed that plant species diversity mirrors change in environmental severity along this high-elevation transect, which is in line with recent reviews on trends in plant richness with increasing altitude (Rahbek 1995; Korner 1999; Chapter 1). Odland and Briks (1999), working in western Norway, found maximum richness within the upper forest zone at 600–700 m and consistent reductions up to the mid-alpine zone at elevation of 1800 m. Mark et al. (2000), who studied Mount Armstrong in New Zealand, found negligible changes in plant richness at lower altitudes but a steady reduction above the treeline up to 2200 m. Along our transect on the Tibetan Plateau, plant richness and diversity index decreased almost 3-fold with altitude increasing from 3200 to 4300 m. The reduction in plant richness with latitude corresponds to the vegetation pattern of the Tibetan Plateau and China in general (Hou and Zhang 1980), but species numbers are very low compared to other mountain regions of the world. This may be the consequence of combined effects of elevation (low temperature) and low precipitation (Wang et al. 2002). Given this small species pool, we would expect to find little functional redundancy within these plant communities, hence making them vulnerable to damage following the loss of only a few species (the insurance hypothesis of biodiversity) (Yachi and Loreau 1999).

Acknowledgements

This research was supported by the National Key Project for Basic Research (G19980840800) and the China's National '10th Five-Year' Scientific and

Technological Key Programme (2001 BA606A-2). We thank Zhao Xingquan and Liu Jianquan for suggestions that lead to clarifications of various aspects in an earlier version of the manuscript, and Zhou Xingming for his help on identification of plant species.

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