Plant species richness and composition in a trans-Himalayan inner valley of Manang district, central Nepal

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Species richness normally decreases with increasing elevation. However, a hump and a plateau have been documented in species richness curves in the Nepal Himalaya. We sampled species richness and composition in 80 plots located in the north and south aspects of the dry valley of Manang, a trans-Himalayan inner valley of Nepal, between 3000 and 4000 masl. We used regression and ordination to relate species richness and composition to the physical environment. *Pinus wallichiana*, *Juniperus indica*, *Abies spectabilis*, *Betula utilis* and *Salix* species are the dominant tree species. *B. utilis* is found only in the moist north aspect and *Juniperus* species are more common in the dry south aspect. Moisture is the most important determinant of species richness and composition. At the local level, our results show a plateau in species richness at the elevation range of 3000–4000 masl. There were significantly more species on the north aspect than on the south.

Key words: aspect, altitude, beta-diversity, ordination, species richness, soil moisture

Species richness is currently the most widely used measure of diversity (Stirling and Wilsey 2001). It is a simple and easily interpretable indicator of biological diversity (Peet 1974, Whittaker 1977). A complex of various factors determines species richness (Schuster and Diekmann 2005). Numerous studies have examined the relationships between plant species richness, climate and spatial variables. In broader scale, plant diversity correlates with size of area (Rosenzweig 1995), latitude (Currie and Paquin 1987), elevation (Stevens 1992, Merganic et al. 2004), precipitation (Whittaker and Niering 1965) and evapotranspiration (Currie 1991, Rohde 1992). Variation of species richness with elevation has been known for a long time. Many studies reported a decline in the number of species with increasing elevation (Brown 1988, Stevens 1992, Begon et al. 1996, Lomolino 2001). However, Rahbek (1995) showed a mid-altitude peak in species richness. Other studies, that found humped relationship between species richness and altitude, include Whittaker and Niering (1975), Liberman et al. (1996), Grytnes and Vetaas (2002) and Carpenter (2005).

Grytnes and Vetaas (2002) analyzed plant species richness along the Himalayan altitudinal gradient in Nepal. They concluded that interpolated species richness in the Himalaya showed a hump-shaped structure. The maximum richness of flowering plants of Nepal has been found between 1500 and 2500 masl. A study of total species richness from ca. 300 to 6000 masl in Nepal indicated a very little variation between 3000 and 4000 masl (Grytnes and Vetaas 2002) generating a high-elevation plateau. Observing this pattern of species richness on large scale, the aim of present work was to test this hypothesis on local level by sampling in a dry inner valley of Nepal Himalaya. The altitudinal range considered for the present work falls under the range of this plateau. The null hypothesis for the study was that there is no change in species richness between 3000 and 4000 masl.

Although the interpolated species richness gives one value for each elevation band, it is well known that richness may vary at different aspect in mountainous environment (Ferrer-Castan and Vetaas 2003). Aspect significantly influences richness and composition of plants. Literatures show that the primary impacts of aspect are expressed through regulating energy budgets and site moisture relationships. However, there is less generality in the effects of these impacts on the expression of vegetation (Bale et al. 1998). Mostly the north facing aspects get more moisture than the south facing aspects in the Himalayas (Vetaas 2000). In our knowledge, no studies have been done so far on the influence of aspect on species richness in the dry inner valley of Nepal Himalaya. The main aims of the present study are: (1) to describe plant species composition and relate it to environmental factors using ordination; (2) to test null hypothesis deduced from the interpolation, of no change in richness in between 3000 and 4000 masl; and (3) to evaluate the effect of aspect on species richness and composition.

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Materials and methods

Study area The study area, a part of Annapurna Conservation Area, lies in Manang district of Nepal in the northwest Central Himalayas (**Figure 1**). The U-shaped inner valley extends east to west and is situated between 28°37’56” and 28°39’55” N latitude and 83°59’83” and 84°07’97” E longitude. The valley is surrounded by the Annapurna range on the south; Manasalu on the east; Peri, Himlung and Choya on the north; and Damodar and Muktinath on the west. The elevation ranges from 3000 to 3500 masl and the climate is dry, characteristic of the trans-Himalayan region. Due to the rain shadow of the Annapurna massif, the mean annual precipitation is ca. 400 mm (ICIMOD 1995). Average maximum and minimum temperatures, recorded at Jomsom (the nearest meteorological station approximately 12 km west of the study area with similar climatic conditions) were 7.9°C and –1.75°C in winter and 22.6°C and 14.15°C in summer, respectively (DHM 1999). Snow covers the valley during winter. Soil moisture decreases from east to west in the valley, and the south facing slopes are significantly drier than those facing north (Bhattarai et al. 2004). The Marsyangdi River drains the valley.

Vegetation is dominated by *Pinus wallichiana*. On the north aspect *P. wallichiana* is abundant from the lower belt up to 3500 masl, above which *Abies spectabilis* and *Betula utilis* are common. *Juniperus indica* and *Rosa sericea* with other shrubs are dominant on the dry south facing slopes (Miehe 1982). The ground layer consists of scattered patches of thorny cushion plant species such as *Caragana*, *Astragalus* with species of *Primula*, *Saxifraga* and *Androsace*. The riverbanks are occupied by *Salix*, *Populus* and *Hippophae*

Table 1. DCA summary

Axes	1	2	3	4
Eigenvalues	0.451	0.298	0.218	0.144
Lengths of gradient	3.045	2.844	2.182	2.156
Species-environment correlation	0.855	0.865	0.595	0.444
Cumulative % variance of species data	9.7	16.1	20.8	23.9

Table 2. Inter-set correlation of main underlying environmental gradients with CA – axes

Axes	1	2	3
Altitude	0.51	0.70	–0.027
Aspect	0.62	–0.41	0.32
Slope	0.15	–0.08	–0.05
Canopy	0.20	–0.69	0.22
pH	–0.17	0.26	–0.63
Moisture	0.77	0.056	0.32

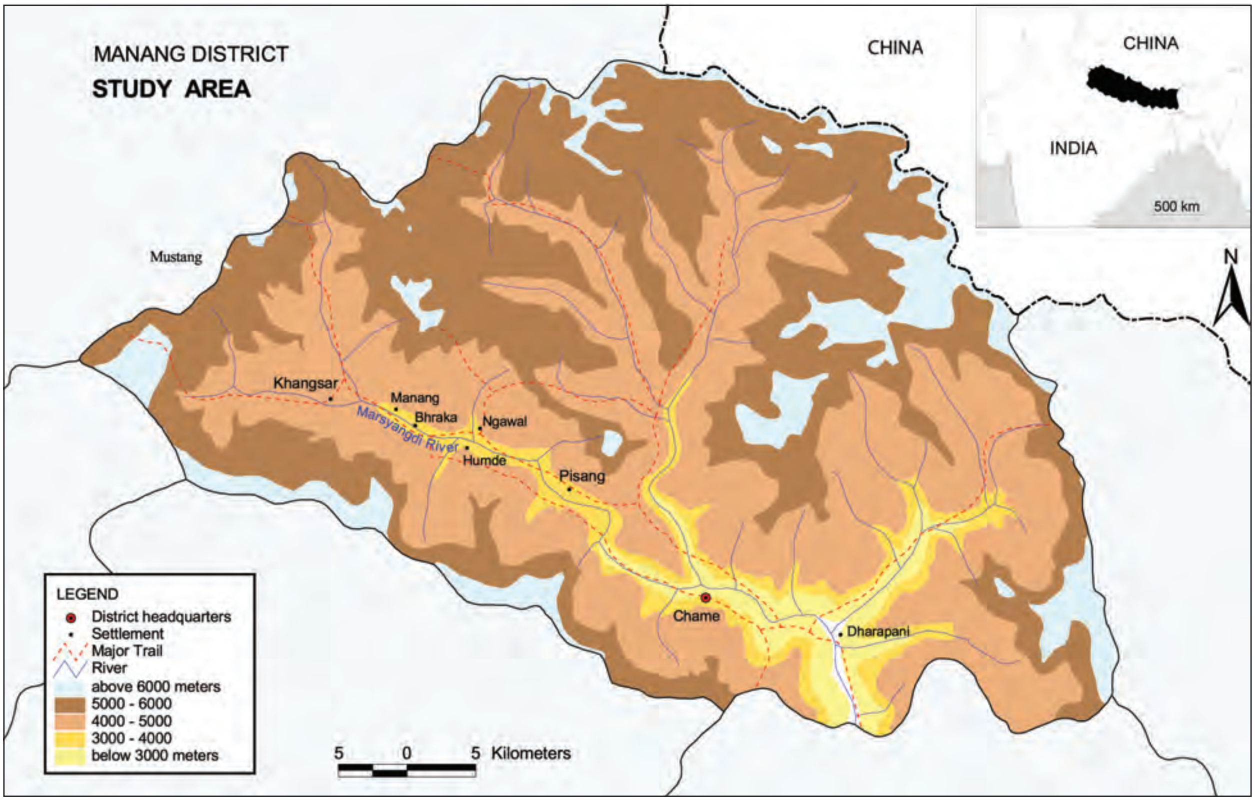

Figure 1. Location of the study area: Upper Manang, a trans-Himalayan dry inner valley in Manang, Central Nepal. (Source: Pawan Ghimire, Department of Geography, University of Bergen)

Table 3. Total species richness

Altitudinal range (masl)	Total species	Total species in N aspect	Total species in S aspect	Species common in both	Species only in N aspect	Species only in S aspect
3200 – 3300	31	22	17	8	14	9
3300 – 3400	36	21	28	13	8	15
3400 – 3500	33	25	18	10	15	8
3500 – 3600	31	24	13	6	18	7
3600 – 3700	29	21	14	6	15	8
3700 – 3800	29	21	12	4	17	8
3800 – 3900	34	26	15	7	19	8
3900 – 4000	39	29	20	10	19	10
Total	68	58	46	36	22	10

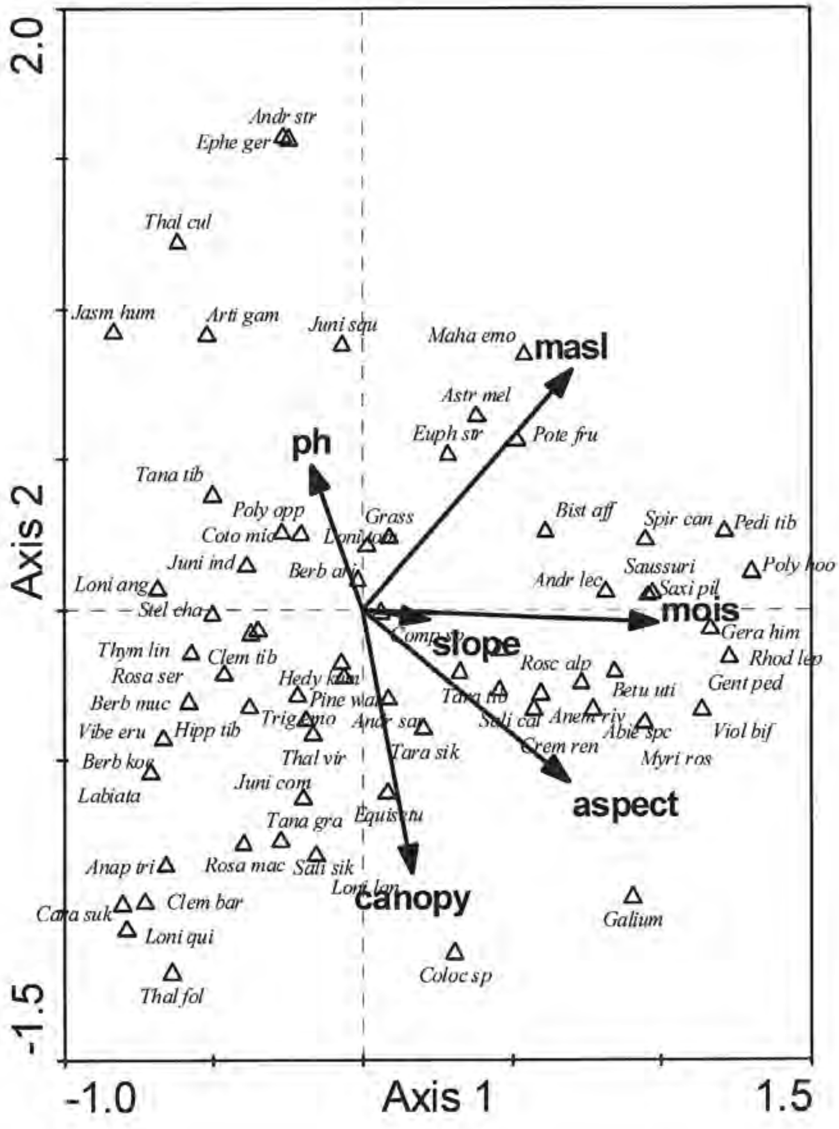

Figure 2. Ordination biplot diagram for species and environmental variables. Plots are displayed by triangles and species are labeled by the first four letters of the generic name and three letters of the species name. Complete plant names are given in Appendix 1. Right side of the axis 1 represents north aspect and left side represents south aspect of the study area.

species. *Picea smithiana* and *Tsuga dumosa* grow on at few locations on the north aspect of the valley.

Field sampling Data on species composition and richness of vascular plants were collected from 80 plots during May and June 2004. Plots (10 m x 10 m) were located using a stratified random sampling design. The sampling was done at 100 m intervals from 3200–4000 masl on the north and south aspects of the valley. Individuals of all species rooted in the plots were counted. The following environmental variables were assessed for each plot: percentage of canopy cover of each tree species (visual estimation), pH and moisture of soil (using a DM 15 gauge, Takemura Electric Works Ltd., Japan), elevation (using an altimeter), and slope (with a clinometer). The nomenclature follows Hara et al. (1978, 1982), Hara and Williams (1979), and Press et al. (2000). All the voucher specimens have been deposited at the Tribhuvan University Central Herbarium (TUCH), Kathmandu, Nepal.

Numerical methods We used ordination to analyze species composition and beta diversity. Detrended correspondence analysis (DCA) is a widely used indirect ordination method (e.g. Økland and Eilertsen 1996, Exner et al. 2002, Lepš and Šmilauer 2003) and provides an effective approximation of the underlying environmental gradients (ter Braak 1995). DCA (Hill and Gauch 1980) was used to describe the total species composition and differences between the two aspects and to estimate the compositional gradient length in SD-units (i.e. beta diversity) (Hill 1973, Lepš and Šmilauer 2003). A preliminary analysis showed SD-unit greater than two and no arch-effect; we used correspondence analysis (CA) to relate species composition to the environmental factors. This was done on the total data set (80 plots) and on the two aspects separately (n = 40).

We also performed regression on the total data set in order to analyze species richness. We used species richness as the response variable and the principal environmental factors (moisture, aspect, pH, canopy) as explanatory variables. We checked distribution on normal Gaussian and Poisson models and selected the former as more suitable. We also performed separate analyses for each aspect in relation to canopy cover, elevation and moisture. The difference in mean species richness between the two aspects was tested by student t-test. We analyzed the data using S-PLUS (Anonymous 2002), as well as CANOCO version 4.5 (ter Braak 2002) and its graphical programme CANODRAW (Smilauer 2002).

Results

Species composition DCA results (**Table 1**) show that the compositional gradient lengths of the first and second axes are 3.0 and 2.8 (eigenvalues 0.451 and 0.298), respectively. The DCA summary reveals that the first gradient is by far the longest, explaining 9.7% of the total species variability, whereas the second and higher axes explain much less. *Pinus wallichiana* was the only dominant tree species found on both north and south aspects. It is located near the central position of the species plot of ordination diagram (**Figure 2**). *Juniperus* species were located towards the negative side of first axis, i.e. on the dry side, while *Betula utilis* and *Abies spectabilis* appeared towards positive side of first axis, which is moister. *B. utilis* was reported only from the north aspect. Other woody species as *Rosa sericea* and *Lonicera* species were found at low elevations of both aspects, while *Rhododendron lepidotum* was noticed at high elevation of the north aspect. At least one or two species of *Berberis* were reported throughout the altitudinal gradient. Among herbs, *Polygonatum oppositifolium*, *Stellera chamaejasme*, *Androsace* spp., *Potentilla fruticosa*, and *Primula* spp. were common.

Correspondence analysis (CA) revealed that moisture, soil pH and canopy cover are the main underlying environmental gradients for species composition. The first and second axes are well correlated with the environmental factors ($r = 0.855$ and 0.865, respectively) and the correlation for the other axes is considerably lower (not shown). Moisture has the strongest correlation with the first axis (**Table 2**, **Figure 2**). The second axis correlates with canopy cover and the third axis with pH. The south aspect is relatively dry with high pH (6.8). The two spatially independent factors – elevation and aspect – were correlated with both first and second axes.

Species richness Sixty eight plant species belonging to 50 genera and 31 families (**Appendix 1**) were recorded. The number of species increased from 3200 to 3400 masl, followed by a gradual decrease up to 3800 masl. Above 3800 masl, the number of species again increases towards high elevation (3900–4000 masl, **Table 3**). In general, however, variation in species richness as function of elevation between 3000 and 4000 masl is not significant, and a high-elevation plateau in richness is found. Species richness is correlated with moisture ($r = 0.232$, **Figure 3**). Normally, south aspect is dry and north aspect is moist. Mean species numbers on the south and north aspects are 10.0 and 11.8, respectively. Species richness is significantly higher on the north aspect than on the south ($t = -2.86$, $p = 0.005$ for 78 df). The total number of species reported from the north aspect is 58, with beta diversity 3.10 and eigenvalue 2.7. The total number of species from the south aspect is 46 with beta diversity 2.97 and eigenvalue 2.1. In total 36 species are common to the both aspects (**Table 3**).

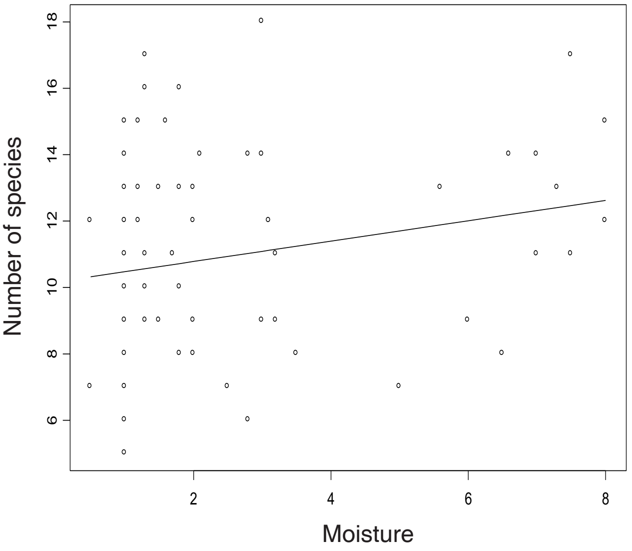

Figure 3. Correlation of total species richness with moisture (arbitrary unit), r = 0.232

Discussion

A monotonic decline in the number of species with increasing elevation has often been considered a general pattern (Brown 1988, Stevens 1992). However, our results indicate that species richness does not follow this pattern in our study sites. A plateau in species number is observed between 3000 and 4000 masl. This is consistent with patterns for overall interpolated species richness in the Nepal Himalaya found by Grytnes and Vetaas (2002) and Vetaas and Grytnes (2002). Studies that have employed the interpolative method on elevation gradients are becoming more common, as for example Fleishman et al. (1998) for butterflies and Grytnes and Vetaas (2002) for plants. Our empirical results confirm that there is a little change in species richness between 3000 and 4000 masl. The small variation in species number may be due to seasonal movement of animals. Livestock (yak, horse, mule, sheep and goats) are brought to alpine pasture to graze during the summer months of April to September (Bhattarai et al. 2004) and stay in the valley bottom during the winter. Seed dispersal via animal dung, hooves and coats (Sykora et al. 1990, Poschlod et al. 1998, Moe 2001) may be important in reducing disparities in species number along the elevation gradient.

The striking high-elevation plateau of species richness might seem anomalous, but similar patterns have been found previously, particularly in ornithological surveys. The species richness of birds in Manu National Park of Peru (Patterson et al. 1998) and also in Bolivia (Herzog et al. 2005) show similar plateau with identical richness values. However, this phenomenon is still not well understood (Herzog et al. 2005). Gill et al. (1999), describing the changes of plant diversity after fire, mention a period of plateau formation in species richness. Fire is not used as a management tool at our study site. Although there were occasional forest fires, their influence on species richness is uncertain.

Moisture is the main environmental factor impacting plant species richness and composition. There is a significant ($r = 0.232$) relationship between moisture and species richness. Moisture is positively correlated with canopy and negatively correlated with pH (**Figure 2**). Soil pH is also related to the availability of soil nutrients, but has no apparent relation to species richness. Increase in species richness from acidic to neutral soil is common in temperate forests (Palmer 1990, Pausas 1994) and a pattern of richness increasing with higher pH has been reported in the Arctic tundra (Gough et al. 2000). Grime (1973) found that the maximum number of species in unmanaged grassland occurs at a pH of 6.1– 6.5, with species richness declining in both acidic and alkaline soils. Canopy is also a significant factor, probably through its influence on the light intensity reaching the ground, as suggested by several authors (e.g., Spurr and Barnes 1973, Tilman 1985).

Aspect regulates the quantity and duration of soil moisture, partly through temperature (Parker 1991). The northern aspect is moister with more canopy cover than the southern aspect; these two factors both have a positive influence on species richness. An understanding of aspect is important in forest management and planning (Bale and Charley 1994), because of its influence on tree diameter growth (Verbyla and Fisher 1989) and forest productivity (Hutchins et al. 1976). The natural forest in the inner valley extends from 3000 to 4200 masl in the north aspect, while its upper limit is below 4000 masl in the south aspect. Aspect also relates with species richness. Since the influence of aspect on species richness in the inner valleys of the Himalayas has not been studied adequately, we could not make further comparisons.

As elevation increases, temperature decreases with the reduction of evapotranspiration on the slopes (Eklund et al. 2000). The elevation contributes to a difference in mean temperature of up to 3.0°C (lapse rate 0.51°C/100 m, Vetaas 2000). In an empirical analysis involving North American plants and animals, Currie (1991) concludes that potential evapotranspiration is the best predictor of animal species richness. For tree species, actual evapotranspiration was shown to be the best predictor of richness, with a monotonically increasing relationship (Currie and Paquin 1987, Francis and Currie 1998).

The beta diversity of the north aspect (3.10) exceeds that of the south aspect (2.1), suggesting greater species turnover on the north side. The turnover in species is mainly attributable to high moisture, along with other supporting environmental factors. Besides the common species found on both the north and south aspects, a total of 22 species reported from the north aspect were not found in the south aspect. In dry habitats, species number increases towards the relatively wetter areas, as observed by Kassas and Zahran (1971) in Egypt, and by Vetaas (1993) in Sudan. In New Zealand total tree species richness was found to increase with soil and atmospheric moisture (Leathwick et al.1998). In dry and semi arid areas moisture is often the limiting factor, and thus has a strong influence on species richness (Olsvig-Whittaker et al. 1983, Belsky et al. 1989). The difference in microclimate between the north and south aspects is associated with differences in the composition and richness of species, which can be compared with the findings of Pook and Moore (1966) on the influence of aspect on the composition and structure of forest on Black mountain, Canberra.

In short, total species richness shows a plateau between 3000 and 4000 masl at the local level. Species richness is significantly higher on the north facing slope than on the south facing slope. It also can be concluded that moisture and factors influencing evaporation (i.e. canopy and aspect), are the main environmental factors influencing species composition and richness in the dry inner valley of the trans-Himalaya.

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APPENDIX: 1. Plants recorded from sampled plots

Abbreviation	Plant name	Family
Abie spe	*Abies spectabilis* (D. Don) Mirb.	Pinaceae
Anap tri	*Anaphilis triplinervis* (Sims.) C. B. Clarke	Compositae
Andr leh	*Androsace lehmannii* Wall. ex Duby	Primulaceae
Andr sar	*Androsace sarmentosa* Wall.	Primulaceae
Andr str	*Androsace strigillosa* Franch.	Primulaceae
Anem riv	*Anemone rivularis* Buch.-Ham. ex DC.	Ranunculaceae
Arti gam	*Artemisia gemelinii* Web. Ex Stechm	Compositae
Astr mel	*Astragalus melanostachys* Benth. ex Bunge.	Leguminosae
Berb ari	*Berberis aristata* DC.	Berberidaceae
Berb koe	*Berberis koehneana* C.K. Schneid.	Berberidaceae
Berb muc	*Berberis mucrifolia* Ahrendt	Berberidaceae
Betu uti	*Betula utilis* D. Don	Betulaceae
Bist aff	*Bistorta affinis* (D.Don) Greene	Polygonaceae
Cara jub	*Caragana jubata* (Pall.) Poir.	Leguminosae
Cara suk	*Caragana sukiensis* C.K.Schneid.	Leguminosae
Clem bar	*Clematis barbellata* Edgew.	Ranunculaceae
Clem tib	*Clematis tibetana* Kuntze	Ranunculaceae
Colo sps	*Colocacea* species	Araceae
Comp sps	Composite species	Compositae
Coto mic	*Cotoneaster microphyllus* Wall. ex Lindl.	Rosaceae
Crem ren	*Cremanthodium reniforme* (DC.) Benth.	Compositae
Ephe ger	*Ephedra gerardiana* Wall.ex Stapf	Ephedraceae
Equi sps	*Equisetum* species	Equisetaceae
Euph str	*Euphorbia stracheyi* Boiss.	Euphorbiaceae
Gali sps	*Galium* species	Rubiaceae
Gent ped	*Gentiana pedicellata* (D.Don) Griseb.	Gentianaceae
Gera him	*Geranium himalayense* Klotzsch	Geraniaceae
Gras one	Grass species	Gramineae
Gras two	Grass species	Gramineae
Hedy kum	*Hedysarum kumaonense* Benth. ex Baker	Leguminosae
Hipp tib	*Hippophae tibetana* Schltdl.	Elaeagnaceae
Jasm hum	*Jasminum humile* L.	Oleaceae
Juni com	*Juniperus communis* Pall.	Cupressaceae
Juni ind	*Juniperus indica* Bertol.	Cupressaceae
Juni squ	*Juniperus squamata* Buch.-Ham. ex D.Don	Cupressaceae
Labiatae	*Labiatae* species	Labiatae
Loni ang	*Lonicera angustifolia* Wall. ex DC.	Caprifoliaceae
Loni lan	*Lonicera lanceolata* Wall.	Caprifoliaceae
Loni qui	*Lonicera quinquelocularis* Hardw.	Caprifoliaceae
Loni tom	*Lonicera tomentella* Hook. f. & Thomson	Caprifoliaceae
Maha emo	*Maharanga emodi* (Wall.) A. DC.	Boraginaceae
Myri ros	*Myricaria rosea* W.W.Sm.	Tamaricaceae
Pedi tib	*Pedinogyne tibetica* (C.B.Clarke)Brand	Boraginaceae
Pinu wal	*Pinus wallichiana* A.B.Jacks	Pinaceae
Poly hoo	*Polygonatum hookeri* Baker	Liliaceae
Poly opp	*Polygonatum oppositifolium* (Wall.) Royle	Liliaceae
Pote fru	*Potentilla fruticosa* var. *rigida* (Wall. ex Lehm.) Wolf.	Rosaceae
Prim den	*Primula denticulata* Sm.	Primulaceae
Rhod lep	*Rhododendron lepidotum* Wall. ex D. Don.	Ericaceae

Rosa mac	*Rosa macrophylla* Lindl.	Rosaceae
Rosa ser	*Rosa sericea* Lindl.	Rosaceae
Rosc alp	*Roscoea alpina* Royle	Zingiberaceae
Sali cal	*Salix calyculata* Hook. f. ex Andersson	Salicaceae
Sali sik	*Salix sikkimensis* Andersson	Salicaceae
Saus del	*Saussurea deltoidea* (DC.) Sch. Bip.	Compositae
Saxi pil	*Saxifraga pilifera* Hook. f. & Thomson	Saxifragaceae
Spir can	*Spiraea canescens* D. Don	Rosaceae
Stel cha	*Stellera chamaejasme* L.	Thymeleaceae
Tana gra	*Tanacetum gracile* Hook. f. & Thomson	Compositae
Tara sik	*Taraxcum sikkimense* Hand.- Mazz.	Compositae
Tara tib	*Taraxacum tibetanum* Hand.- Mazz.	Compositae
Thal cul	*Thalictrum cultratum* Wall.	Ranunculaceae
Thal fol	*Thalictrum foliolosum* DC.	Ranunculaceae
Thal vir	*Thalictrum virgatum* Hook. f. & Thomson	Ranunculaceae
Thym lin	*Thymus linearis* Benth.	Labiatae
Trig emo	*Trigonella emodi* Benth.	Leguminosae
Vibu eru	*Viburnum erubescens* Wall. ex DC.	Sambucaceae
Viol bif	*Viola biflora* L.	Violaceae