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RESIDUAL VALUE ANALYSES OF THE MEDICINAL FLORA OF THE WESTERN HIMALAYAS: THE NARAN VALLEY, PAKISTAN

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Abstract

Statistical analyses of the medicinal flora of the Naran Valley in the Western Himalayas were performed using Moerman's methods and Principal Components Analysis (PCA). The results demonstrate that the valley's indigenous people utilize medicinal plants in a systematic way. Sixty-eight families of plants were identified during the study, of which 52 contained one or more species of medicinal value. The standard deviation for residual values of all the 68 families was 0.993 and the results of the residual analysis revealed that seven of these plant families were overused by the local people, indicated by residual values greater than the standard deviation. Residual values obtained from a regression analysis of plant species with their medicinal uses showed that the families with the highest rank were *Polygonaceae, Gentianaceae, Lamiaceae, Rosaceae* and *Plantaginaceae,* indicating their medicinal importance. By comparison, *Poaceae, Boraginaceae, Primulaceae, Salicaceae,* and *Ranunculaceae* were the lowest ranking families, containing few species of medicinal value. Although a few of the most species-rich families in the valley contained a high number of medicinal plants and hence displayed high residual values, some other species-rich families contained few or no species of medicinal value. For example, the third largest family, *Poaceae*, is the lowest in terms of its residual value, while the largest family, *Asteraceae*, contains only seven species noted as having medicinal uses. Sixteen plant families in the valley contained no species with reported medicinal use, while seven families contained only one species with medicinal value. In contrast, all of the species in several of the least species-rich families were recorded as having a medicinal use. The results of a Principal Components Analysis showed a gradient of medicinal plant use along the valley. Using robust statistical approaches, our study provides a clear indication that the indigenous people of this Western Himalayan valley utilize wild plants according to their traditional knowledge and not on the basis of plant abundance.

Introduction

The Himalayas stretch over some 2500 km and comprise one of the Earth's most complex, diverse and remarkable biomes, characterized by a comparatively harsh climate, a strong degree of resource seasonality and a high diversity of plant communities and species (Kala & Mathur, 2002; Oommen & Shanker, 2005). In north-western Pakistan, three of the world's highest mountain systems congregate together i.e., the Hindukush, Karakoram and Western Himalaya, ensuring high floral diversity and phytogeographical interests.

The benefits obtained by humans from nature are termed ecosystem services (De Groot *et al*., 2002; Millennium Ecosystem Assessment, 2003; Mooney *et al*., 2004; Butler & Oluoch-Kosura, 2006; Carpenter *et al*., 2006; Boyd & Banzhaf, 2007; Jordan *et al*., 2010; Seppelt *et al*., 2011). The mountain ecosystems of the Himalayas provide a range of basic regulatory services, including water and air purification, climate regulation, waste disintegration, soil fertility and regeneration, and biodiversity support. The ecosystems also provide goods and services in the form of food, grazing land and fodder for livestock, fuel wood, timber and medicinal products. These services ultimately contribute to agricultural, socio-economic and industrial activities (Kremen, 2005; Boyd & Banzhaf, 2006; Zobel *et al*., 2006).

Due to their isolated location, rugged landscapes and critical geopolitical situation, many of the more remote mountainous valleys in the Himalayan region have not yet undergone detailed vegetation studies. Furthermore, most of the botanical accounts that have been published comprise inventories based on qualitative data either for ethnobotanical purposes or to support the writing of floras (Dickoré & Nüsser, 2000; Ahmad *et al*., 2009, Signorini *et al*., 2009). Nevertheless, several studies have highlighted the threat to plant biodiversity and vegetation-related ecosystem services as a result of over exploitation, e.g. through forest cutting, livestock grazing and the collection of fodder, edible and medicinal plant species. The use of plants in the preparation of traditional medicines has a long history in this region and provides a vital service in areas remote from orthodox health care services. In order to develop appropriate management strategies for the conservation and sustainable use of plant resources, it is crucial to understand how those traditional uses interact with the existing biodiversity. Any such study should, necessarily, involve an assessment of the use of plants by indigenous people, in order to identify the plant species and families of greatest medicinal importance. The use of statistical methods in vegetation description and particularly in relation to changes in use patterns, has emerged as a valuable approach in ethnoecological studies in recent years. Such knowledge contributes to an improved understanding of regional biogeography, conservation strategies and provides a quantitative basis for further ecological and ethnobotanical studies. To date, however, only a limited number of studies have used modern statistical techniques in order to provide quantitative descriptions of plant use along geo-climatic or cultural gradients. Yet these approaches can help to elucidate the main determinants of regional vegetation use patterns (Dasti *et al*., 2007; Malik & Husain, 2008; Wazir *et al*., 2008; Saima *et al*., 2009).

In this study, we combined data derived from a botanical survey of the vegetation of the Naran Valley in the Western Himalaya with the results of a questionnaire survey of plant use conducted amongst the residents of the twelve main settlements in the valley. Using several forms of statistical analyses, we assessed which plant species had a medicinal value and compared this with their abundance based on the vegetation survey. We also explored the amount of plant collection taking place within the valley and the local people's perceptions of whether the abundance of medicinal species was increasing or declining.

Study area (The Naran valley): The Naran is a mountainous valley in North West Pakistan, some 270 km from the capital, Islamabad (34°54.26´ N to 35°08.76´ N latitude and 73°38.90´ E to 74°01.30´ E longitude; elevation range 2450 to 4100 m above mean sea level). The entire area is formed by rugged mountains on either side of the River Kunhar, which flows in a northeast to southwest direction down the valley to the town of Naran. The River Kunhar has its source at Lake Lulusar near the Babusar pass at an elevation of 3455 m. Geographically, the Naran Valley is located on the extreme western boundary of the Himalayan range, at the edge of the Hindukush range, which starts to the west of the River Indus (Fig. 1). The rocks of the valley can be subdivided into basement rocks of amphibolites, marble, dolomite, quartzite, and deformed granite (Parrish *et al*., 2006; Clift *et al*., 2008). Climatically, the Naran Valley has a dry temperate climate with distinct seasonal variations. Total average annual precipitation is low at only 900-1000 mm with heavy snowfall in winter. Summers remain cool and relatively dry as high mountains to the south of the valley limit the entrance of monsoon rains. Melting snow (May to September) is the main source of water for both plant growth and the River Kunhar. During most of the year temperatures remain below 10°C.

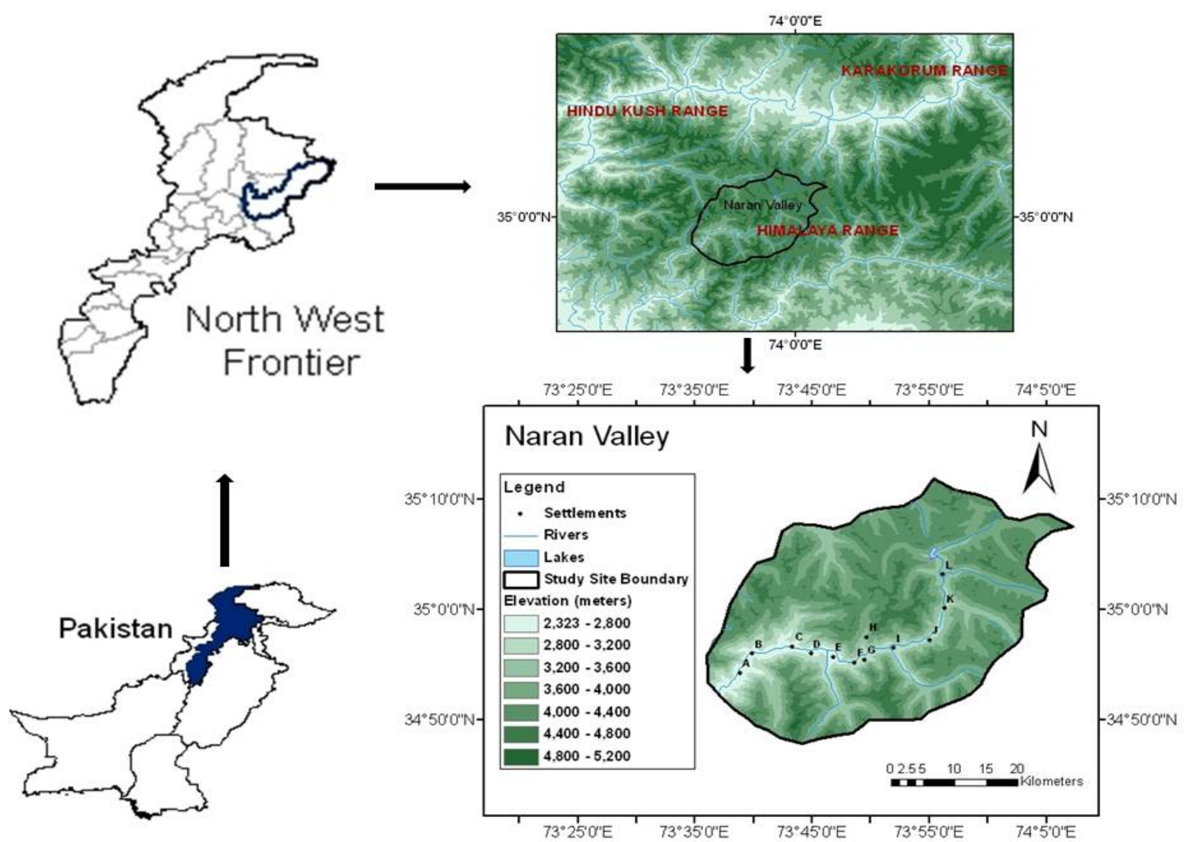

Fig. 1. Physiographic map showing the position of the Naran Valley (project area); location of its settlements, altitudinal zones, the River Kunhar, originating lake and tributary streams.
(Elevation data was obtained from the ASTER GDEM, a product of METI and NASA)

Methodology

Data collection was conducted in two phases in summer 2009 and 2010.

1. A botanical and phytosociological assessment of the vegetation in the valley was carried out during 2009. A total of 198 plant species of 68 families were recorded (Khan *et al*., 2011b).

2. Each of the 12 main settlements in the valley was visited. Meetings were arranged with village heads or councillors and permissions were obtained for questionnaire-based interviews with a sample of the local residents on their use of native plants. A local community member, who knew the norms and traditions of the indigenous society, was engaged as a guide. Ten houses in each of the 12 settlements (a total of 120) were selected randomly for the interviews. A mixture of qualitative and quantitative data collection methods were adopted in order to obtain local knowledge about the native plant species and their uses, with a particular emphasis on medicinal plants, their collection, the parts of the plants used and their medicinal applications, following the methods of previous

ethnobotanical surveys (Phillips *et al*., 1994; Rossato *et al*., 1999; Cunningham, 2001; Martin, 2004; Da Cunha & De Albuquerque, 2006; Ferraz *et al*., 2006; De Albuquerque, 2009). Plant species photographed during the first field campaign in 2009 (Khan *et al*., 2011b) were shown to the interviewees where this was felt necessary.

Data analyses

Principle component analysis (PCA): Principle Components Analysis (PCA) was carried out using CANOCO to assess the usage gradient at the various locations along the valley, following Dalle *et al.,* (2002). Average numbers of plants with a medicinal use in each locality were calculated in MS EXCEL according to the CANOCO requirements. Data attribute plot as a utility in PCA was used to analyze the pattern and extent of medicinal plant use along the valley as described by Toledo *et al.,* (2009).

Residual value and regression analyses: Moerman methods of comparative analyses (Moerman, 1991) were used to compare the medicinal plants against the check list of all vascular plant species obtained during the vegetation survey (see Khan *et al*., 2011b) in order to obtain residual values using SPSS 18 (Colman, 2008; Peter & Kellie, 2010). As the project was initiated principally to quantify and classify plant occurrence and use along an environmental gradient (Khan *et al*., 2011b), the Moerman method was chosen as the best approach to correlate the ethnobotanical data with the species occurrence data (Bryman & Cramer, 1997). It was hypothesized that local people used the medicinal species according to their indigenous knowledge and not on the basis of the plant's abundance in the region. Moerman's method of residual values analyses helps to answer such questions by giving predicted and residual values for each group (Amiguet *et al*., 2006; Bennett & Husby, 2008). Regression analyses and curve fit were used to illustrate the relationships between the 198 plant species in 68 families (independent variable) and the 102 medicinal species within 52 families (dependent variable) (Table 1).

Table 1. Regression model summary.

Model	R	R Square	Adjusted R square	Change statistics				
				R Square change	F Change	df1	df2	Sig. F Change
1	0.790	0.624	0.618	0.624	109.476	1	66	0.000

Results

Ethnomedicinal plant resources: The respondents of the questionnaire survey comprised of a representative cross-section of people in the 12 settlements. Among the 120 informants, 87 were male and 33 were female. The largest proportions of the respondents were elders, i.e. above 40 years of age (81.6%) and only 18.3% were below the age of 30. These results reflect the reality that indigenous knowledge is well established in the population but seems to be decreasing amongst the younger generation. Analyses showed that 102 plant species belonging to 52 families (51.5% of the total plants) were used for medicinal purposes. Lamiaceae, with nine species, was the most represented family, followed by Polygonaceae and Rosaceae with eight species each. Details of the individual medicinal plant species and their residual values are given in Table 5.

Results of the principle component analysis (PCA) and cultural gradient analysis: PCA data attribute plots illustrate the use pattern of plants for medicinal purposes along the valley. These coincide both with climatic and cultural gradients. Climatic conditions favor the vigorous growth of vegetation in the lower valley where people use plants as medicine for their own use as well as for marketing purposes. In the more remote, upper valley, grazers utilize high altitude meadow vegetation extensively during the short summer, with livestock being moved onto these areas immediately after snow-melt. The sizes of the circles in the PCA plots show the strength of plant use at each locality along the valley (along increasing altitudinal as well as latitudinal gradients). These plots show that there is a gradient of traditional plant utilization along the valley. The PCA results further indicate that people living in the middle of the valley show the strongest preference for medicinal plant collection, which may be linked to the availability and richness of the plants at mid-altitude, the lack of medical care facilities, and an intact culture that still retains considerable ethnobotanical knowledge (Table 2 & Fig. 2).

Table 2. Description of the first four axes of the PCA for the various categories of medicinal services of vegetation (using informants' data at various localities along the valley).

Axes	1	2	3	4	Total variance
Eigen values	0.802	0.128	0.045	0.015	1.000
Cumulative percentage variance of species data	80.2	93.1	97.6	99.2	

Residual value analyses of medicinal plant families in the valley: The standard deviation for residual values of all the 68 families was 0.993 (Table 3), and the results of the residual analyses indicate that seven families are overused by the dwellers of the area and hence have residual values greater than the standard deviation (r^2 = 0.624; p = 0.000) (Table 4). The top five families with highest residuals are Polygonaceae, Gentianaceae, Lamiaceae, Rosaceae and Plantaginaceae. The lowest residual values were recorded for the families Salicaceae, Ranunculaceae, Primulaceae, Boraginaceae and Poaceae. Although few of the abundant families contain high numbers of medicinal plants, a few have no or very few medicinal species. For example, the third largest family, Poaceae, is the lowest in terms of residual values whilst the largest family, Asteraceae, also has a low residual value (Table 5). On the contrary, all of the plants in some of the least abundant families have a medicinal use, supporting the hypothesis that people utilize the plants according to their traditional knowledge rather than their abundance in the vegetation. For example, 31 families with only one or two species are all used medicinally in the area. Sixteen plant families in the region have no reported medicinal plants, while seven have only one representative species.

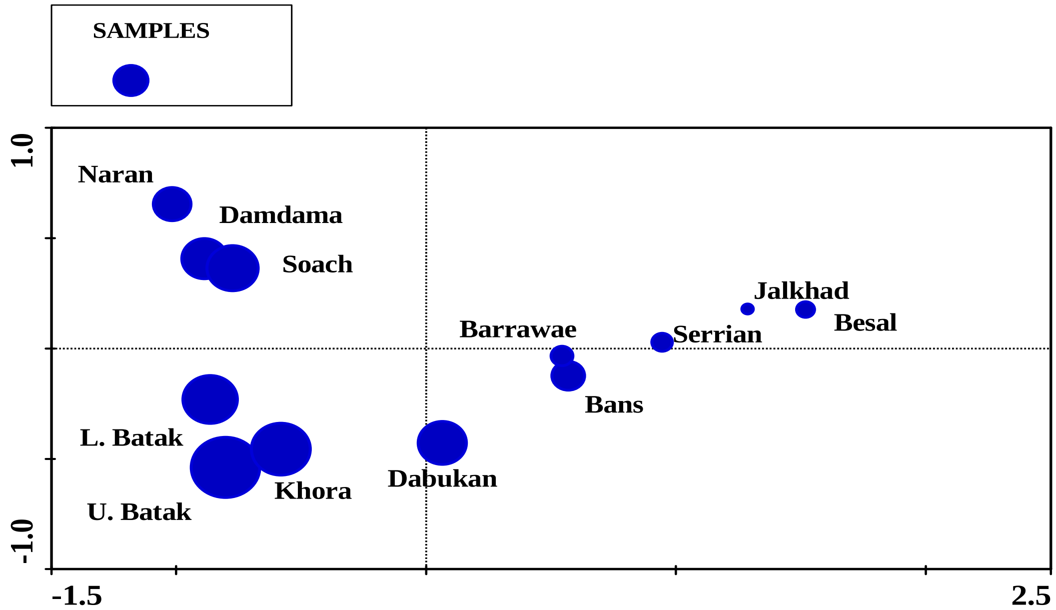

Fig. 2. PCA data attribute plot showing the medicinal uses of plant species at various localities along the valley (altitudinal and latitudinal gradient).

Table 3. Summary of the residuals statistics using regression analyses.

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted value	0.68	7.65	1.51	1.559	68
Residual	-5.035	3.400	0.000	1.210	68
Std. predicted value	-0.534	3.933	0.000	1.000	68
Std. residual	-4.129	2.788	0.000	0.993	68

Table 4. Model summary for regression plot and parameter estimates.

Equation	Dependent variable: Medicinal species (Med. spp.) model summary					Parameter estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	0.624	109.476	1	66	0.000	0.247	0.435

The independent variable is representative species

Top-ranking families: The residual values (Table 5) and regression plots (Fig. 3a & b) confirm that Polygonaceae represent the top-ranking family, followed by Gentianaceae and Lamiaceae. All of these families include typical alpine species of high medicinal value. *Rheum australe, Rumex nepalensis, Bistorta amplexicaulis* and *Oxyria digyna* (Polygonaceae), *Gentiana kurroo, Gentiana moorcroftiana* and *Swertia ciliata* (Gentianaceae), *Thymus linearis, Mentha longifolia, Origanum vulgare* and *Salvia moocroftiana* (Lamiaceae) are the most important medicinal plants. The 4th and 5th top residual scoring families are Rosaceae (*Fragaria nubicola, Crataegus oxycantha* and *Rosa webbiana*) and Plantaginaceae (*Plantago lanceolata* and *Plantago major*).

Low-ranking families: The five lowest-ranking families are Poaceae, Boraginaceae, Primulaceae, Ranunculaceae and Salicaceae. Poaceae, the grass family, although highly abundant in the valley and an important family for grazing animals, have no species of medicinal value and hence are at the bottom of the residual values table. Boraginaceae represent the second least medicinally important family in the region (Table 5 and Fig. 3a & b).

Table 5. Residual values analysis (Regression analysis) of 68 plant families of the Naran Valley showing predicted and residual values. The number of plant species for each family referred to the quadrat (first year) data set (Representative Species) and the questionnaire data set (Medicinal Species).

Case No.	Family name	No. of repres. spp.	No. of medic. spp.	Predicted value	Residual value
1.	Polygonaceae	10	8	4.60	3.401
2.	Gentianaceae	6	6	2.86	3.141
3.	Lamiaceae	13	9	5.91	3.094
4.	Rosaceae	14	8	6.34	1.659
5.	Plantaginaceae	3	3	1.55	1.447
6.	Fumariaceae	8	5	3.73	1.271
7.	Pinaceae	4	3	1.99	1.012
8.	Caprifoliaceae	2	2	1.12	0.882
9.	Caryophyllaceae	2	2	1.12	0.882
10.	Orchidaceae	2	2	1.12	0.882
11.	Saxifragaceae	2	2	1.12	0.882
12.	Cupressaceae	3	2	1.55	0.447
13.	Alliaceae	1	1	0.68	0.317
14.	Asparagaceae	1	1	0.68	0.317
15.	Asphodelaceae	1	1	0.68	0.317
16.	Berberidaceae	1	1	0.68	0.317
17.	Betulaceae	1	1	0.68	0.317
18.	Chenopodiaceae	1	1	0.68	0.317
19.	Colchicaceae	1	1	0.68	0.317
20.	Convolulaceae	1	1	0.68	0.317
21.	Dioscoreaceae	1	1	0.68	0.317
22.	Ephedraceae	1	1	0.68	0.317
23.	Equisetaceae	1	1	0.68	0.317
24.	Euphorbiaceae	1	1	0.68	0.317
25.	Grossulariaceae	1	1	0.68	0.317
26.	Hippocastanceae	1	1	0.68	0.317
27.	Hypericaceae	1	1	0.68	0.317
28.	Iridaceae	1	1	0.68	0.317
29.	Malvaceae	1	1	0.68	0.317
30.	Oleaceae	1	1	0.68	0.317
31.	Paeoniaceae	1	1	0.68	0.317
32.	Podophyllaceae	1	1	0.68	0.317
33.	Sambucaceae	1	1	0.68	0.317
34.	Solanaceae	1	1	0.68	0.317
35.	Trilliaceae	1	1	0.68	0.317
36.	Ulmaceae	1	1	0.68	0.317
37.	Urticaceae	1	1	0.68	0.317
38.	Valerianaceae	1	1	0.68	0.317
39.	Violaceae	1	1	0.68	0.317
40.	Apiaceae	4	2	1.99	0.012
41.	Adiantaceae	2	1	1.12	-0.118
42.	Balsaminaceae	2	1	1.12	-0.118
43.	Fumariaceae	2	1	1.12	-0.118
44.	Scrophulariaceae	2	1	1.12	-0.118
45.	Liliaceae	3	1	1.55	-0.553
46.	Pteridaceae	3	1	1.55	-0.553
47.	Rubiaceae	3	1	1.55	-0.553
48.	Asteraceae	17	7	7.65	-0.647
49.	Acanthaceae	1	0	0.68	-0.683
50.	Aceraceae	1	0	0.68	-0.683
51.	Cyperaceae	1	0	0.68	-0.683
52.	Ericaceae	1	0	0.68	-0.683
53.	Juglandaceae	1	0	0.68	-0.683
54.	Morinaceae	1	0	0.68	-0.683
55.	Onagraceae	1	0	0.68	-0.683
56.	Orobanchaceae	1	0	0.68	-0.683
57.	Parnassiaceae	1	0	0.68	-0.683
58.	Plumbaginaceae	1	0	0.68	-0.683
59.	Tamaricaceae	1	0	0.68	-0.683
60.	Brassicaceae	6	2	2.86	-0.859
61.	Crassulaceae	2	0	1.12	-1.118
62.	Juncaceae	2	0	1.12	-1.118
63.	Salicaceae	2	0	1.12	-1.118
64.	Ranunculaceae	12	4	5.47	-1.47
65.	Geraniaceae	3	0	1.55	-1.553
66.	Primulaceae	7	1	3.29	-2.294
67.	Boraginaceae	8	1	3.73	-2.729
68.	Poaceae	11	0	5.04	-5.035

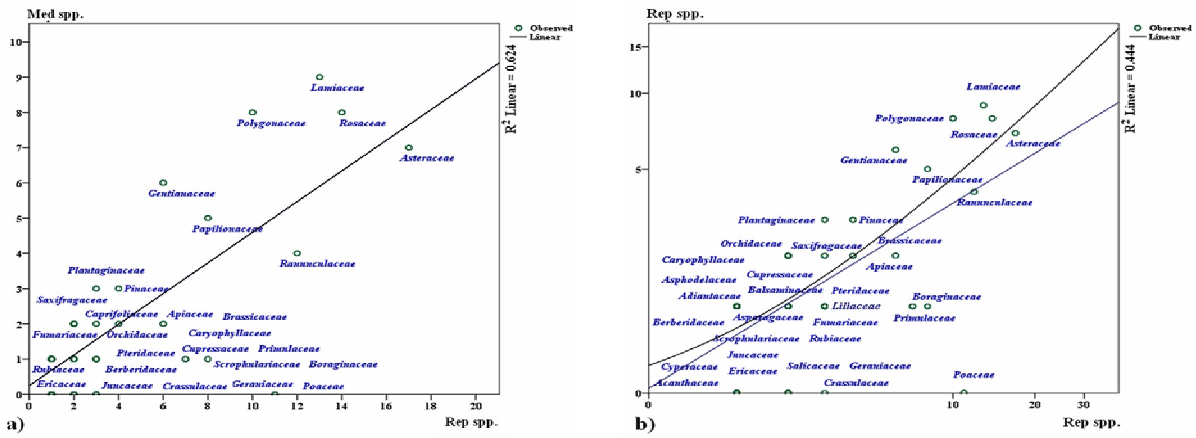

Fig. 3. (a) Regression and (b) log regression plots showing families with number of medicinal plant species versus the total species recorded in quadrat survey (N = 68; p = 0.000; r^2 = 0.624 & 0.444).

Discussion

Medicinal plant resources and ecosystem services: The use of plants to cure diseases is as old as human history and around 20% of the plant species in the world are estimated to be used in health care systems (Baillie *et al.*, 2004). Although each medicinal species has a value in traditional health care systems, those which are endangered, endemic or less abundant also have a high conservation importance, and over-collection for medicinal purposes could threaten their survival. In this study, 4 of the reported medicinal species i.e., *Dioscorea deltoidea, Podophyllum hexandrum, Cypripedium cordigerum* and *Dactylorhiza hatagirea* are of global conservation importance and listed by CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). One or more of these species have also been reported in a few other ethnobotanical studies from the Himalaya, Hindu Kush and Karakorum (Shinwari & Gilani, 2003; Ahmad *et al*., 2009; Shaheen *et al*., 2011). Some species encountered in our study are endemic to the Himalayas e.g., *Cedrus deodara, Aesculus indica, Acer caesium, Ulmus wallichiana, Aster falconeri, Corydalis govaniana, Pedicularis pectinata, Salvia moocroftiana* and *Vicia bakeri,* whilst some are rare in the region e.g., *Aconitum heterophyllum, Aconitum violaceum, Ephedra gerardiana, Hypericum perforatum, Indigofera heterantha,* and *Paeonia emodi*; greater attention should be given to their sustainable use. In addition to medicinal uses, these species also provide other services, including timber, fuel and fodder and thus may be under threat from a variety of uses.

In the high valleys of the Himalayas, indigenous people have a long established system of plant-based health care. Their use of different plant parts and the recipes used to prepare medicines are based on long experience and knowledge. Our results indicate that the elders have a more accurate knowledge about medicinal plant uses and their preparation than the young, supporting the findings of other studies (Shinwari, 1996; Balemie & Kebebew, 2006; Khan *et al*., 2011a). There was a decreasing trend in the medicinal plant species in the valley; this was attributed to the rising human population in the valley, increasingly extensive grazing by livestock, habitat loss, multipurpose collection and carelessness.

Medicinal plant families in the study area: The top 5 families identified as being overused by the results of the residual analyses were Polygonaceae, Gentianaceae, Lamiaceae, Rosaceae and Plantaginaceae. Among the lowest-ranking families in terms of its medicinal use was Poaceae, although members of this family have a high value for grazing and fodder purposes (Amiguet *et al*., 2006; Bennett & Husby, 2008). In contrast to a few other studies, our findings show that Orchidaceae are considered by the local people to have a relatively high medicinal value, which is supported by the findings of another study (Amiguet *et al*., 2005). Asteraceae, the most abundant family, were ranked number 48 in terms of medicinal use, whilst the 5th most species-rich family, Poaceae, occupied the lowest position. In contrast, Plantaginaceae moved up from 17th position in terms of abundance to 5th position, owing to their high medicinal value; likewise, Caryophyllaceae was 23rd in abundance but 9th in medicinal importance. Residual value analyses show that the indigenous people of the Naran Valley use local plants for medicinal purposes based on their value and not on their availability. Interestingly, most of the least abundant families are utilized frequently by the local people, supporting the hypothesis that people utilize the plants according to traditional knowledge and not abundance. For example, 31 poorly represented families with only one or two species are all used medicinally in the area.

A novel approach to the study of medicinal plant species: Plant biodiversity directly or indirectly provides services to mankind and it is therefore imperative that it is evaluated, managed and safeguarded (CBD, 2006). Many people in the developing world depend heavily on natural resources for a wide range of services (Uprety *et al*., 2010). A number of previous studies in the Himalayas and the Hindukush region have merely provided inventories of medicinal plant species e.g. (Ahmad *et al*., 2009; Ali & Qaiser, 2009; Negi *et al*., 2010) and much less attention has been given to quantitative ethnobotany. We have adopted this comparatively new method to assess plant uses in one Himalayan valley, using an approach that has previously only appeared in published work from South American countries (Rossato *et al*., 1999; Bermudez *et al*., 2005; Da Cunha & De Albuquerque, 2006; Ferraz *et al*., 2006; Goleniowski *et al*., 2006). In this paper we link the medicinal services of the inventoried flora to both the local traditional knowledge and species abundance. Furthermore, the perception (ecological knowledge) of the local people was documented to support an assessment of whether the populations of medicinal plant species were increasing or decreasing, whilst Principle Component Analysis (PCA) and data attribute plots were used to understand and link the cultural-use gradient with ecological gradients. The application of these techniques can help to identify the patterns of medicinal services provided by plant biodiversity (Garibay-Orijel *et al*., 2007; Abraão *et al*., 2008), thus providing valuable insights for the design of plant conservation management and planning policies.

A recent study has pointed out that to date, most ecosystem service studies have been carried out in the developed world, with only 13% of publications on this topic from Asia and the Pacific (Vihervaara *et al*., 2010). Similarly, only a few authors have pointed out the importance of plant biodiversity in mountain regions as a basic driver of ecosystem services (Nakashizuka, 2004; Hermy *et al*., 2008; Christensen & Heilmann-Clausen, 2009; Rey Benayas *et al*., 2009). Our study is, therefore, one of the first in the Himalayan region that attempts to integrate knowledge of plant biodiversity with a cultural gradient of plant use in order to assess current anthropogenic trends and pressures for both immediate and long term management planning. We argue that this type of survey, which combines ecological and cultural knowledge, is essential in order to produce the best possible management, preservation and conservation strategies for the plant species in this region.

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