Medicinal plants of Nepal: Distribution pattern along an elevational gradient and effectiveness of existing protected areas for their conservation

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This study explores patterns of medicinal plant species richness along an elevational gradient in Nepal and the effectiveness of existing protected areas for their conservation. We used published data on the distribution of medicinal plants. The number of medicinal plants and the number of protected areas present in each 100 m elevation band were collated by interpolation. We tested the number of protected areas and the number of species as the response variables against elevation as a predictor variable. To explain the relationship between the total medicinal plant richness and their different life forms with elevation and protected areas, we used generalized additive models (GAMs) and scatter plots. The elevational distribution of medicinal plants as a whole and disaggregated into different life forms revealed hump-shaped patterns. The maximum richness of medicinal plants was found at an elevation of 1100 m a.s.l. but the maximum numbers of protected areas were found at elevations between 3000-3500 m a.s.l. There was negative correlation between the altitudinal distribution of protected areas and medicinal plants in Nepal. This study suggests that the protected areas of Nepal were less concentrated where medicinal plants diversity was rich.

Key words: Elevation gradient, generalized additive model, medicinal plants, species richness

With a wide range of topographic features and climatic conditions in Nepal, one can find large environmental variation (from the humid lowland forests to glaciated mountain tops). This variation has resulted in isolated localities that host a large number of plant species. So far, around 7000 species of flowering plants have been documented for Nepal (DPR, 2001). Of these, around 1792 species (including lichens and fungi) were used for medicinal purposes (Baral and Khurmi, 2006). However, the number of medicinal plants in Nepal is still uncertain. Almost 60% of the world population and 80% of the population in the developing countries rely on traditional medicines (Shrestha and Dillion, 2003).

In a developing country like Nepal, the majority of the people in the rural areas rely mostly on plants and plant products for their traditional "medicines" or drugs and primary health care needs. Demand for medicinal plants have been increasing due to their having no side-effects, easy availabilities at affordable prices and sometimes being the only source of health care available to the poor. The source of medicinal plant is usually the nearby forest which is being depleted because of forest clearing for agriculture, land for settlement of the growing population, developmental activities and demand for forest based raw materials (Manandhar, 1995; Chaudhary, 1998) so many species are already threatened due to collection pressures (Ghimire *et al.*, 2005).

The majority of the studies till date have focused on systematic documentation of useful plants but there is a lack of quantitative studies on the distribution pattern on medicinal plants, especially within existing protected areas. The study of the relationship between species richness and elevation is important for conservation and management of species diversity (Grytnes, 2003) because the lack of detailed knowledge about distribution patterns of species and ecosystems leads to problems in conserving species (Hunter and Yonzon, 1993).

Relationship between species richness and elevation have been determined using different methods for variety of taxa in different parts of the world (*see*

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Rahbek, 2005; Garu *et al.*, 2007) and along the Himalayan elevational gradient (Vetaas and Grytnes, 2002; Bhattarai *et al.*, 2004; Carpenter, 2005; Grau *et al.*, 2007; Acharya, 2008). But, studies on elevational pattern of medicinal plants and its relationship with protected areas have not been carried out. Medicinal plants represent all life forms and taxonomic groups of plants.

So, this study might document the patterns for the medicinal plants with different life forms. The main objectives of this study are: 1) to find out the distribution patterns of medicinal plants along the elevational gradients in the Nepal Himalaya, 2) to compare these patterns with patterns found for plants and plants groups from the same area, so as 3) to ascertain any relationship between the elevational distribution of protected areas and the elevational distribution of medicinal plants of Nepal.

Materials and Methods

Biogeographical location and climate of study area

Nepal (26^0 22' N to 30^0 27' N latitude, 80^0 40' E to 88^0 12' E longitude), the central Himalaya is a narrow Himalayan strip that consists of five east-west running ranges: Terai, Siwaliks, Mahabharat, High mountains and High Himalaya (LRMP, 1986). Across this short North South distance, the elevation ranges from about 60 m to 8848 m (highest peak of the world) and comprises tropical to alpine climatic zones. The medicinal plants are distributed from 100 m to 6,000 m a.s.l. (DPR, 2007).

Nepal harbours a wide range of climatic conditions. However, the climatic conditions can be broadly divided into two types: dry winter period and wet summer period (Shankar and Shrestha, 1999). The climatic condition of Nepal is dominated by the precipitation from the Bay of Bengal summer monsoon. The amount and distribution of this precipitation, the duration and altitudes of cloudiness vary considerably in different parts. The amount of rainfall gradually decreases from east to west, but increases from the plains to certain elevations between 800 to 2000 m a.s.l. to the north and then decreases.

Data Source and Interpolation

We collected information of medicinal plants from secondary sources. The elevation ranges of medicinal plants were collected from DPR (2007). Information on sixty species assigned to various risk categories: critically endangered, endangered, insufficiently known, nearly threatened, vulnerable, rare, threatened and data deficient were collected from DPR (2006). This was the latest book on medicinal plants of Nepal with the information on their elevational distribution. The medicinal plants were distributed from 100 m to 6000 m a.s.l. To examine the relationship between species richness and elevation, the overall elevation range between 100 and 6000 m was divided into 60, 100-m elevation interval, vertical elevation bands. The number of species present in each elevation band was estimated by interpolation (Vetaas and Grytnes, 2002; Bhattarai *et al.*, 2004). A species was determined to being "present" in every 100-m intervals of its upper and lower elevation limits. For example, *Dactylorhiza hatagirea* with its elevation limit between 2800 and 4000 m, was assumed to be present in each elevation band of 2800, 2900, 3000, 3100, 3200, and so on up to 4000 m (*see* Bhattarai *et al.,* 2004). We used the term species richness for the total number of medicinal plant species present in each 100-m elevation band. To find the number of protected areas occurring in each 100-m elevation band, the altitudinal range of each protected areas was determined from *Nepal Biodiversity Strategy* (HMGN/MFSC, 2002). The interpolated elevation range was converted to dummy variable by ascribing "1" for presence and "0" for absence and the number of conservation sites per 100 m elevation band was estimated (Crawley, 2005).

Statistical analysis

This is an exploratory study with elevation (meters above sea level) as the main predictor variable, so we used Generalized Additive Models (GAMs) (Hastie and Tibshirani, 1990) with up to four degrees of freedom to explore the overall pattern of species richness with elevation. We used elevation as an explanatory variable and species richness and the number of conservation sites as response variables. Species richness data were considered to follow a Poisson distribution as it is a count (discrete) data (Crawley, 2005) which requires a logarithmic link. However, because of overdispersion, a quasi-Poisson model was used (Crawley, 2005) with a logarithmic link. We used an *F*-test to check the significance of models because this is more robust when there is overdispersion (Crawley, 2005). We used $R_{2.8.1}$ (R Development Core Team, 2008) for regression analysis and graphical representations.

Results and discussions

Life form spectrum of medicinal plants of Nepal

The latest report on the total number of medicinal plants and their elevational range counted 697 species (DPR, 2007). These medicinal plants belonged to different life forms: trees, shrubs, herbaceous, climbers and some were lichens and mushrooms (Figure 1).

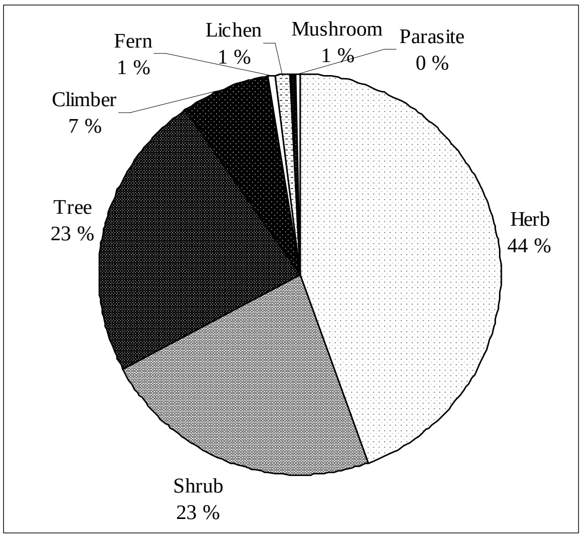

Figure 1: Different life forms of medicinal plants.

Distribution of medicinal plants in different ecological regions and along the elevation gradients

The medicinal plants were found growing between the elevations of 100 m to 6,000 m a.s.l. The distribution of medicinal plants along different ecological regions of Nepal is tabulated in Figure 2.

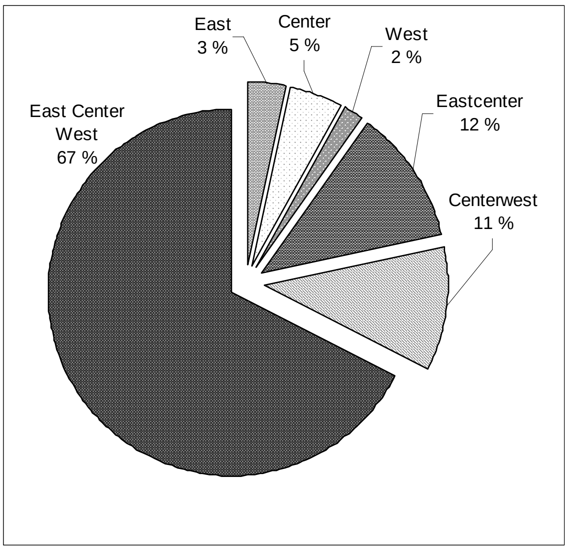

Figure 2: Distribution of medicinal plants in different regions of Nepal

The variation in species richness of total and of different life forms of medicinal plants along the elevation gradient is presented in Figure 3. The uppermost elevations for the growth of different life forms of medicinal plants were different. The uppermost elevation for the growth of trees, shrubs, herbaceous forms and climbers were 4500 m, 5000 m, 6000 m and 3300 m a.s.l, respectively. The total and different life forms of species showed hump-shaped patterns of distribution along the elevation gradient of Nepal. The optimum richness of different life forms was also different. The maximum richness of total medicinal plants was observed at an elevation of 1100 m a.s.l. Similarly the maximum richness of trees, shrubs, herbaceous forms and climbers were found at elevations of 1000 m, 1000 m, 1300 m and 900 m a.s.l, respectively (Figure 3). Because of overexploitation, sixty species have been assigned to various conservation risk categories: critically endangered, endangered, insufficiently known, nearly threatened, vulnerable, rare, threatened and data deficient. The maximum richness or concentration of these threatened medicinal plants peaked at 3500 m a.s.l. (Figure 3f).

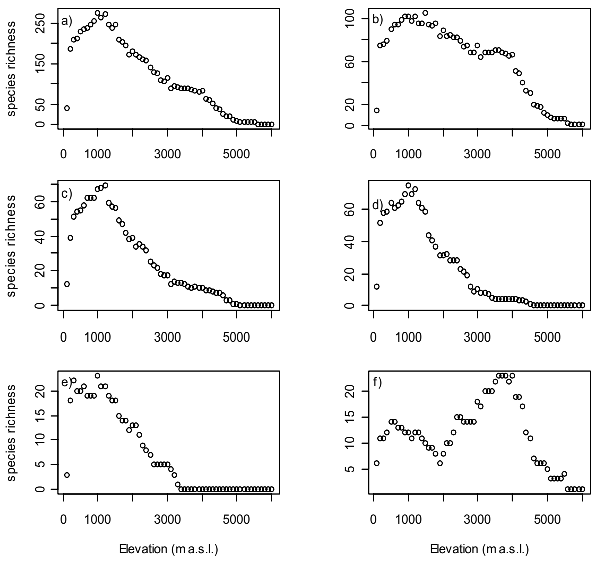

Figure 3: Relationship between different life forms a) total b) herbs c) shrub d) tree e) climber f) threatened of medicinal plants of Nepal with elevation (m a.s.l.). (Note: Vertical axis has different scales).

Species richness

We found hump-shaped patterns of medicinal plant species richness along the elevation gradient in Nepal Himalaya (Figure 3a) peaking at 1100 m a.s.l, which was about 400 m below the prediction made by Vetaas and Grytnes (2002) for flowering plants.

Similar unimodal patterns have been observed for flowering plants (Grytnes and Vetaas, 2002), ferns (Bhattarai *et al.,* 2004), liverworts and mosses (Grau *et al.,* 2007) and orchids (Acharya, 2008). This suggests that hump-shaped pattern is the common pattern (Rahbek, 2005). This result also supports the findings made by Malla and Shakya (1999), Hamilton and Radford (2007) and Ghimire (2008) that maximum numbers of medicinal plants were found within the elevation of 1000-2000 m a.s.l.

Medicinal plants included plants of different life forms (trees, shrubs, herbs, climber etc.). When analyzed for different life forms of medicinal plants, the present study did not find results similar to Bhattarai and Ghimire (2006). The maximum richness of medicinal plants with different life forms: shrub, herbaceous and climber were found at lower elevations than those obtained from the analysis of Bhattarai and Ghimire (2006). This might be because they had included smaller numbers of species in their analysis (143 species vs 647 in this investigation). However, there was consistency in the maximum richness of medicinal plants ascribed to tree life forms as in the result of Bhattarai and Ghimire (2006).

To explain the causes of these patterns, many hypotheses have been proposed; however, climatic variables seem to be the most important for explaining species-richness patterns with elevation, especially in broad-scale studies (Odland and Birks, 1999; Bhattarai and Vetaas, 2003; Sanders *et al.,* 2007). The maximum richness of species will occur at locations with maximum rainfall and optimum energy conditions. So, the maximum richness of medicinal plants at the elevation of 1100 m a.s.l. was due to the optimum water energy dynamics (Bhattarai and Vetaas, 2003).

Mid-elevation peak in species richness may be the result of large scale mass effect (Shmida and Wilson, 1985). The mid elevation receives inputs from both the lower elevations and higher elevations. So, mass effect or source sink dynamics may be important in influencing variation in species richness within an elevation gradient (Grytnes and Vetaas, 2002). This is the first comprehensive and quantitative study on medicinal plants of Nepal where the maximum richness of plant species was observed at the elevation of 1100 m a.s.l. The peak of maximum richness of medicinal plants contrast with the richness peak of ferns at 1900 m and of vascular plants, which had a maximum richness between the elevations of 1500 to 2500 m a.s.l.

Medicinal Plants vs Conservation areas

There are nine national parks, three wildlife reserves, one hunting reserve, three conservation areas and nine buffer zones covering a total area of about 19.42% of total area of Nepal (Table 1). The protected areas in Nepal are distributed from 75 m to 8848 m a.s.l. Maximum numbers of protected areas were found between 3000 m to 3500 m a.s.l (Fig. 4).

Table 1: Conservation areas of Nepal and their altitudinal range in Nepal

S.N.	Protected areas of Nepal	Elevation (m a.s.l.)	
		low	high
1	Annapurna Conservation Area	1000	8092
2	Dhorpatan Hunting Reserve	2850	7000
3	Kanchanjunga Conservation Area	1200	8598
4	Khaptad National Park	1000	3276
5	Koshi Tapu Wildlife Reserve	90	90
6	Langtang National Park	792	7245
7	Makalu Barun National Park	435	8463
8	Manaslu Conservation Area	1360	8163
9	Parsa Wildlife Reserve	150	815
10	Rara National Park	1800	4048
11	Bardia National Park	152	1494
12	Chitwan National Park	150	815
13	Shuklaphanta Wildlife Reserve	90	270
14	Sagarmatha National Park	2800	8848
15	Shey Phoksundo National Park	2000	6885
16	Shivapuri National Park	1366	2732

Source: HMGN/MFSC (2002)

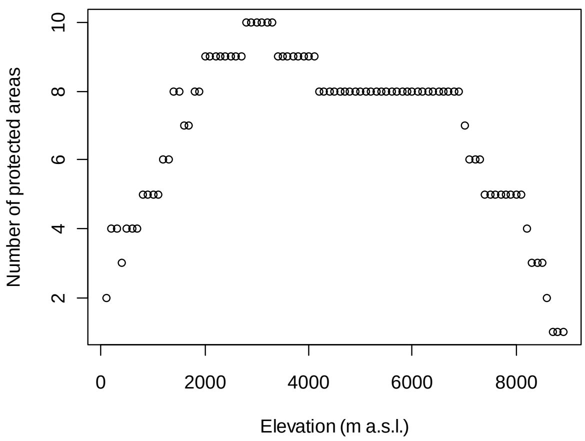

Figure 4: Relationship between numbers of protected area with elevation along an elevation gradient in Nepal.

The number of protected areas increased up to 3000 m and then gradually decreased after 3500 m a.s.l.

There was a strong negative correlation between the total number of medicinal plants and the number of protected areas (r= - 0.46) (Fig. 5a). However, there is a positive correlation between the total number of threatened medicinal plants and the number of protected areas (r= 0.224) (Fig. 5b).

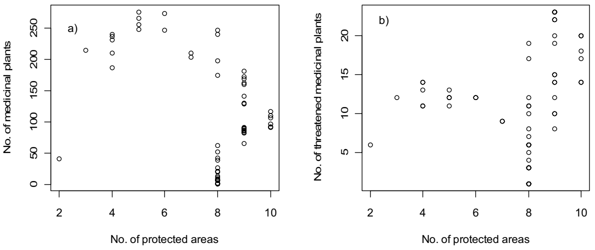

Figure 5: Scatter plot showing the relationship between a) no. of medicinal plants b) no. of threatened medicinal plants with number of protected areas of Nepal.

Protected area and medicinal plant species richness

Till date, there are nine national parks, three wildlife reserves, one hunting reserve, three conservation areas and nine buffer zones covering a total area of about 19.42% of total area of Nepal (Table 1). These protected areas were distributed from 75 m to 8848 m a.s.l. and the maximum numbers of these areas were found between 3000 m to 3500 m a.s.l. But the maximum peak of plant species was found below this elevational range. There was a negative correlation between number of protected areas and number of medicinal plants (Figure 5a). This shows that our conservation efforts are less focused towards plant diversity. Protected areas were located at higher elevations where diversity of plants was less. However, there was a positive correlation between number of threatened medicinal plants and the number of protected areas (Figure 5b). Ghimire *et al.* (2006) also found that the elevations between 3000 m to 4500 m a.s.l. harbour potential medicinal plants for national and international trade and these species are threatened.

Large numbers of medicinal plants in wild are being depleted due to the continuous and haphazard harvesting, without any plans to regenerate and sustain them (Sharma *et al.,* 2004). In Nepal, medicinal plants were collected by people from rural areas; the majority of them do not possess adequate knowledge of natural regeneration and plant habitats. Not only this, the collectors extracted even those medicinal plants which were banned for collection and transportation. According to local traders, the numbers of medicinal plants in their localities had declined in recent years (Acharya and Rokaya, 2005). Some of the high value herbs were threatened with extinction. These included *Dactylorhiza hatagirea, Nardostachys grandiflora, Rauvolfia serpentina, Valeriana jatamansi* (Chaudhary, 1999). The Government of Nepal had banned the collection and transportation of some species; however, these types of ban and restriction have not been effective in the conservation of species and the reduction of the collection amount.

Medicinal plants occur in good densities in national parks and reserves where harvest has been prohibited or restricted (Sharma *et al.,* 2004). However, Ghimire *et al.* (2005) reported the collection of two threatened species, *N. grandiflora* and *Neopicrorhiza scrophulariiflora* even from national parks and buffer zones. A complete checklist of flora present in each protected area of Nepal has not yet been prepared (Bhattarai and Ghimire, 2006). If the species is distributed across a large number of middle hill districts, collection and trade of medicinal plants is too high from lowland districts or Terai districts (Olsen, 2005). If this collection situation continues, then a large number of medicinal plants will be threatened from lower belts where the diversity has been high. Another reason for higher extraction of medicinal plants from lower belts is because these areas are easily accessible.

For the solution for sustainable management, the Government of Nepal has given top priority to 12 rare and high priced plant species (out of total 30 medicinal plant species prioritized for research and development) (DPR, 2006). Farming of these medicinal plants will help ease the supply problems, regularize their trade, provide certifiable products of uniform quality and offer a new source of income to the rural poor. The establishments of herbal farms in the Royal botanical garden (Godavari) and Daman Botanical Garden (Daman) have been successful in conserving medicinal plants found in the respective localities. However, these *ex-situ* conservation efforts are insignificant compared to the vast resources available to the country. Besides, their methods of documentation are poor: the accession of conserved plants has not been maintained properly and methods of propagation have not been properly documented (Sharma *et al.,* 2004). The community forest program, one of the priority programs, aims to produce a wide range of forest products including medicinal plants. In community forestry, people specify their use rights to the management, development and utilization of forest resources. In order to collect more revenue from community forests, community forest user groups are running silvicultural and harvesting activities (Acharya *et al.,* 2006). Instead of growing all plant species in their forests, people are now focusing on a few selected fast growing species. The practice of using a few selected species for fuelwood and the absolute conservation of dominant species in community managed forests may affect the regeneration process and community structure of forests and may also destroy the habitat of valuable medicinal plants. So, community user groups should be well trained about the medicinal plants.

Conclusions

As indicated by the distribution pattern of medicinal plants, the maximum richness of these was observed at the elevation of 1100 m a.s.l. but the maximum protected areas were found at elevations between 3000 to 3500 m a.s.l. The distribution pattern of protected areas did not correspond well with the distribution pattern of medicinal plants. If the medicinal plants of Nepal are to be well protected, it is important that the elevational range where maximum richness of medicinal plants is found should be prioritized for conservation activities.

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