# Patterns in distribution, population density and uses of medicinal plants along the altitudinal gradient in Dhauladhar mountain range of Indian Himalayas

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**We studied the patterns in distribution, population density and uses of medicinal plant species in Dhauladhar mountain range of Himachal Pradesh in Indian Himalayas. The study area was stratified into three zones on the basis of forest types and altitudes. In each zone, quadrats were laid down for sampling of plant species, and the local people were interviewed for gathering information on medicinal uses of plants. A total of 184 plant species were encountered in the sampling plots, of which 86% had medicinal uses. Among woody plant species, the use of bark was highest, whereas in herbaceous species the use of leaf and root was highest for treatment of over 32 groups of diseases. In terms of density, *Pinus roxburghii* was the most dominant tree species in subtropical forests, which declined in temperate regions and was absent in subalpine forests. *Rhododendron arboreum* was the most dominant tree species in temperate region whereas in subalpine forests it was replaced by *Abies pindrow*, in terms of density. *Berberis asiatica* and *Vitex negundo* were the most dominant shrubs in subtropical forests besides *Lantana camera*, whereas *Berberis lycium* dominated the temperate and *Juniperus indica* dominated the subalpine forests. The heavy infestation of *Lantana camera* in sub-tropical forests has degraded the habitats of native medicinal plant species. Spearman's correlation indicates positive correlation between local uses and density of respective medicinal plant species ($P < 0.05$). The results are further discussed in light of medicinal plants conservation in this part of the Indian Himalayas.**

**Keywords:** Altitude, Dhauladhar mountain, Indian Himalayas, medicinal plants, population density, regeneration.

THE Himalayan ecosystem is rich in plant species diversity. Many species are used for treatment of diseases by the local communities[1,2]. Apart from their therapeutic properties, these medicinal plant species maintain the health of an ecosystem as each species has a specific role in the functioning of an ecosystem[3]. The altitudinal and climatic variations make the Himalayan ecosystem unique for availability and distribution of various species[4]. However, the historical dependency of various communities on different forest types across the Himalayan region, especially on medicinal plants, has influenced the density of plant species if not the range of their distribution[5,6]. As the density and distribution of useful plant species affect human life in several interrelated ways, in depth studies on population density and distribution of such plant species must be carried out, especially in the areas inhabited and exploited by human beings. Species diversity may support the stability of ecological services over time[7], whereas declining populations may result in the ecological extinction of such species and loss of services provided by such species to the communities. Besides, the quantification of plants is important as they also provide resources and habitats for many other wild fauna and flora[8,9]. Species richness and density, particularly of medicinal plant species, may further guide policy makers for designing conservation and management strategies and priorities for such a valuable resource[10,11].

Himachal Pradesh, one of the Himalayan states in India, has diverse flora as well as an important position in the socio-cultural and spiritual activities of the rural people for centuries[12]. The state harbours various forest types along the altitudinal gradients[13], which support high medicinal plants diversity[14,15]. Besides sporadic studies[16–18], these forests are least studied, particularly in terms of population density and patterns in distribution of medicinal plant species. In Himachal Pradesh, where multiple forest types along the altitudinal gradients are of ecological and economical significance[19,20], it is important to study these forest types with respect to the distribution of medicinal plant species and their population density along the altitudinal gradient. This may help to understand the pattern of medicinal plants distribution and further need for conservation as it is believed that high biodiversity plays a key role in minimizing anthropogenic impacts on ecosystems[3]. With this background, the

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present study aims to analyse the plant species distribution and density with respect to medicinal plants in the Dhauladhar mountain range of Himachal Pradesh. Besides, the study attempts to explore relations between local uses and population density of medicinal plants.

## Methodology

### *Study area*

The present study was carried out in Kangra district of Himachal Pradesh in India. Kangra district is situated on the southern escarpment of the Dhauladhar mountain range, which extends to the bank of the Beas river in Kullu district of Himachal Pradesh between 31°2–32°5 N and 75°–77°45 E (Figure 1). Kangra district spans an area of 5063 sq. km within the altitudinal gradient from 427 to 6401 m above mean sea level (amsl). The annual average rainfall in this region is about 1539 mm. The annual average maximum temperature of the district is 35°C in the southern part and 25°C in the northern part. Kangra district is one of the most populated districts as it has a population of 1,507,223, which is highest among all districts of Himachal Pradesh (21.98% of the population). The rural population is 94.27%, whereas the urban population is about 5.73%. Kangra district is inhabited by nomadic tribes, locally called Gaddis and the Pahari folks[12]. The area supports rich flora and fauna, with distinct forest types particularly subtropical forests, moist temperate forests (both broad and coniferous) and subalpine forests.

### *Ethnobotanical survey of medicinal plants*

To collect information on various medicinal uses of plant species and their distribution, the study area was divided into three zones on the basis of altitude and forest types, such as, subtropical forests (1000–1500 m), temperate forests (1501–3000 m) and subalpine forests (>3000 m), following Champion and Seth[13]. The fieldwork was carried out from July 2013 to December 2015. Villages were selected randomly in each zone and structured questionnaires and interviews were carried out among different groups of people, i.e. the elders, women, traditional healers and medicinal plants traders to collect information on the use of plant species. Focus group discussions were also organized in the respective villages. The survey was spread across seasons so as to get maximum information.

### *Plant population survey*

To assess the population density and distribution of plant species along the altitudinal gradient, quadrats were laid down in each identified zone, such as, subtropical, temperate and subalpine. The quadrats of 10 × 10 for trees, 5 × 5 for shrubs and saplings and 1 × 1 for herbs and seedlings were laid at equal intervals with the distance of 200 m along the transects radiating out from the villages in each zone. In each sampling quadrat, all plant species were identified and individuals of each species were enumerated. The individuals with cbh >31.5 cm were considered as trees, cbh 10.5–31.4 cm as saplings and cbh <10.5 cm as seedlings. The density was calculated for tree, shrub and herb species.

## Results

### *Plant medicinal uses*

A total of 184 plant species were encountered in the sampling plots during the assessment of population density in the study area (see Supplementary Tables 1–3). These species were distributed across 78 families, of which 71 families belong to angiosperms, 3 families to gymnosperms and 4 families to pteridophytes. Except for 25 species (Supplementary Table 3), the rest of the species were mentioned as medicinally important by the local people. These 159 medicinal plant species were distributed across different life forms (Supplementary Table 4), of which herbs were the most dominated life forms ($n$ = 99), followed by trees ($n$ = 32) and shrubs ($n$ = 28**)**. Different plant parts such as root, leaf, fruit, flower, stem and bark of these 159 medicinally important species were used for the treatment of 32 groups of diseases by the local people in the study areas, of which leaves of the highest number of species ($n$ = 71) were used by the local people, followed by roots ($n$ = 41). Of woody plant species, the use of bark was highest whereas the use of leaf and root of herbaceous species was highest for treatment of diseases. Maximum number of species was used for treatment of muscular pain ($n$ = 28), followed by gastro-intestinal problems ($n$ = 22), skin infections ($n$ = 18) and birth and menstruation ($n$ = 17) related problems.

### *Population density and distribution*

Along the altitudinal gradient, temperate forests contained the highest number of medicinally important tree species ($n$ = 21), followed by subtropical forests ($n$ = 18; see Supplementary Table 1). The subalpine forests contained 8 tree species, of which 3 were used by local people for medicinal purposes. The medicinal shrub species were equally dominant in temperate and subtropical forests whereas their numbers declined to 50% in the subalpine forests. Most of the herbaceous species (70%) were encountered in temperate forests, followed by tropical and subalpine forests (Supplementary Table 2).

*Pinus roxburghii* was the most dominant tree species in subtropical forests in terms of density (544.94 ± 0.09 individuals per ha), which decreased substantially in the

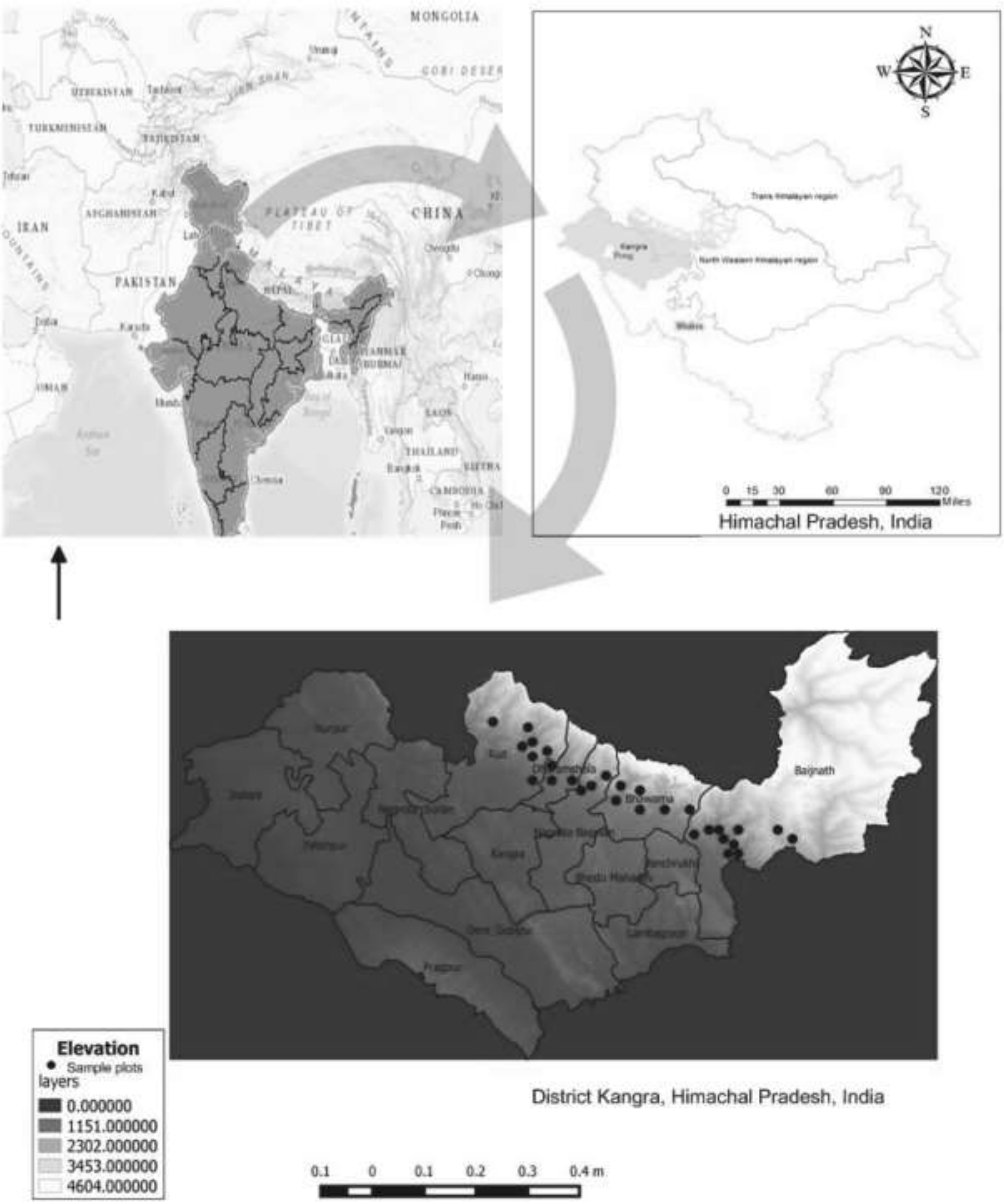


**Figure 1.** Location of the study area.

temperate region (49.63 ± 0.07 individuals per ha) with absence of any individual in the subalpine forests. In the temperate region, *Rhododendron arboreum* was the most dominant tree species (347.76 ± 0.13 individuals per ha) in terms of density, followed by *Quercus semecarpifolia* (190.67 ± 0.12 individuals per ha), *Cedrus deodara* (181.72 ± 0.12 individuals per ha) and *Pyrus pashia* (176.12 ± 0.08 individuals per ha). *Abies pindrow* was the most dominant tree species in subalpine forests in terms of density (320.95 ± 0.14 individuals per ha), followed by *Quercus semecarpifolia* (227.62 ± 0.13 individuals per ha) and *Picea smithiana* (161.90 ± 0.13 individuals per ha). *Abies pindrow, Betula utilis, Picea smithiana, Quercus leucotrichophora, Quercus semecarpifolia* and *Taxus* *wallichiana* were found in both temperate and subalpine regions whereas some tree species such as *Quercus floribunda*, had restricted distribution in subalpine forests.

There was substantial infestation of *Lantana camara*, a weed, in sub-tropical forests, as it was the most dominant shrub species in terms of density (735.58 ± 0.08 individuals per ha). Among the native shrub species, *Berberis asiatica* was the most dominant shrub in terms of density (707.11 ± 0.07 individuals per ha), followed by *Vitex negundo* (637.70 ± 0.08 individuals per ha) and *Murraya koenigii* (576.77 ± 0.07 individuals per ha) in subtropical forests. In temperate forests, *Berberis lycium* was the most dominant shrub species in terms of density (704.48 ± 0.08 individuals per ha), whereas in subalpine forests *Juniperus indica* had highest density (636.19 ± 0.11 individuals per ha).

Herbaceous species were low in number in subtropical forest where *Imperata cylindrica* was the most dominant species in terms of density (1.45 ± 0.06 individuals per $m^2$), followed by *Arisaema tortuosum* (1.16 ± 0.05 individuals per $m^2$) and *Cynodon dactylon* (1.11 ± 0.09 individuals per $m^2$). Temperate forests were rich in herbaceous plant species. *Adiantum venustum* (0.86 ± 0.08 individuals per $m^2$) in temperate forests and *Trillidium govanianum* (0.50 ± 0.47 individuals per $m^2$) in subalpine forests were the most dominant herbs in terms of density. Four species such as *Cirsium verutum, Cyperus rotundus, Digitaria setigera* and *Morina longifolia* were common in all three forest types across the altitudinal gradient. *Cirsium verutum* had high density in the subtropical areas when compared to the other two zones. *Morina longifolia* had high density in the high altitudinal region whereas *Cyperus rotundus* and *Digitaria setigera* were dominant herbs in the temperate region.

### *Regeneration*

In subtropical forests, *Pinus roxburghii* had the highest density of saplings (449 individuals per ha) and seedlings (551 individuals per ha), followed by *Pyrus pashia* (sapling density = 225 individuals per ha and seedling density = 269 individuals per ha). The rest of the tree species showed low density of saplings and seedlings. In temperate forests, the sapling density for *Rhododendron arboreum* (337 individuals per ha) was highest among all tree species, followed by *Quercus semecarpifolia* (156 individuals per ha), *Pyrus pashia* (149 individuals per ha) and *Cedrus deodara* (120 individuals per ha). In subalpine forests, the highest sapling density was recorded for *Abies pindrow* (191 individuals per ha), followed by *Picea smithiana* (134 individuals per ha) and *Quercus semecarpifolia* (108 individuals per ha) (Supplementary Table 5).

Among shrub species in subtropical forests, *Vitex negundo* had the highest density of saplings (672 individuals per ha), followed by *Berberis asiatica* (421 individuals per ha), *Lantana camara* (418 individuals per ha) and *Murraya koenigii* (355 individuals per ha). In temperate forests, *Berberis lycium* showed the highest sapling density (594 individuals per ha) among all shrub species, followed by *Cotoneaster acuminatus* (242 individuals per ha), *Prinsepia utilis* (109 individuals per ha), *Desmodium triflorum* (107 individuals per ha) and *Viburnum nervosum* (101 individuals per ha). In subalpine forests, *Rhododendron campanulatum* was the most dominant shrub species in terms of sapling density (347 individuals per ha), followed by *Juniperus indica* (270 individuals per ha), *Indigofera heterantha* (156 individuals per ha) and *Berberis lycium* (122 individuals per ha).

## Discussion

The present study reveals that Dhauladhar mountain range of Indian Himalayas is endowed with rich diversity of plant species, of which >86% are reported as medicinal plants by the local people. The leaf and root of herbaceous species and bark of woody plant species are highly used plant parts for treatment of diseases. The distribution of plant species indicates their strong relationship with elevation. For instance, among the medicinal tree species, chir pine (*Pinus roxburghii*) dominates the subtropical forest whereas its density declines in temperate forest and it does not grow in subalpine forests due to cold climatic conditions. Besides *Pinus roxburghii* which dominates subtropical forests, *Rhododendron arboreum* and *Quercus semecarpifolia* dominate temperate forests and *Abies pindrow* dominates the subalpine forests. None of the tree and shrub species grows in all three forest types across the altitudinal gradient. The tree species which is predominant in the subtropical forests can grow up to temperate forests but not beyond it in the subalpine forests. Similarly, the tree species that predominate in the temperate forests may grow in subalpine forests as well, but not in the subtropical forests. Three species of *Quercus* such as *Q. semecarpifolia*, *Q. leucotrichophora* and *Q. floribunda*, despite having high density in temperate and sub-alpine forests are not reported to have medicinal properties by the local people. Of these three species, only *Q. leucotrichophora* is reported to be exploited for medicinal purpose by the local people of Uttarakhand[21], one of the neighbouring states of Himachal Pradesh.

The herbaceous vegetation in *Pinus roxburghii* forest was considerably low in number when compared to temperate forests, chiefly dominated by *Rhododendron arboreum* and *Quercus semecarpifolia*, which support 70% of the total herbaceous species in the study area. The moisture content in the rhododendron-oak forests remains higher than *Pinus roxburghii* forests, which is conducive for good undergrowth. Besides, the leaf litter of *Pinus roxburghii* affects the growth of herbaceous plants negatively, and also delays their germination due to allelopathic effects. In contrast, the leaves of *Rhododendron arboreum* increase the germination of herbaceous species, which results in better growth of herbaceous species[22].

The invasion of *Lantana camara*, which emerged as the most dominant shrub species during the present study, is changing the structure and composition of subtropical forests. Since *Lantana camara* prefers relatively warm climatic condition, it has not yet invaded the temperate and subalpine forests. Besides, as *Lantana camara* spreads in the habitats occupied by many important medicinally and ecologically important species, including *Berberis asiatica*, *Vitex negundo* and *Adhatoda vasica*, its continuous proliferation may be crucial for the survival of these important native plant species.


**Figure 2.** Correlation between local uses of medicinal trees and shrubs and their density (per ha) in Dhauladhar mountain range of Indian Himalaya (Pearson correlation = 0.202, $\alpha = 0.05$).


**Figure 3.** Correlation between local uses of medicinal herbs and their density (per $m^2$) in Dhauladhar mountain range of Indian Himalaya (Pearson correlation = 0.126, $\alpha = 0.05$).

Besides providing essential health care services in the form of high number of valuable medicinal plants, these forests supply diverse ecosystem services due to diversity in occurrence of species across the altitudinal gradients. Though the forests in the study area have been undergoing numerous anthropogenic pressures, the relatively fair regeneration of some of the tree species along the altitudinal gradient suggests their tolerance to partial biotic pressures and wider ecological amplitude. Similar observations were made by Saikia and Khan[23] for the rain forests of north east India, and deciduous forests of Chhattisgarh[24] and Madhya Pradesh[25]. The disturbance gradient and altitudes influence tree species richness[5]. The findings of the present study on the assessment of regeneration pattern of tree species corroborate with Kumar *et al.*[18] who reveal that the middle altitudinal forests have relatively fair regeneration when compared to higher altitudes. Further, the trends in tree density along the altitudinal gradient in the present study area do fit the model at the continental scale as described by Carpenter[26] who reports that species density is controlled by climatic variables.

In the present study, the plant density showed positive correlation with the regeneration rate of both seedlings and saplings of trees and shrubs. Besides, the Spearman's correlation indicates positive correlation between local uses and density of medicinal plants ($P < 0.05$) (Figures 2 and 3). This indicates that the number of uses of a species established by the local people over the years also depends on the density of the respective species. High density of a species makes local people establish its high number of uses because of its easy availability when compared to the species having low population density. In the nearby state of Uttarakhand, the high occurrence of *Pinus roxburghii* has made local people explore and establish its various indigenous uses despite the fact that this tree species is not appreciated by many ecologists[27]. Besides density of medicinal plants, there may be other factors which determine identification of the species by local people for multiple indigenous uses.

There are reports on the continuous decline of medicinal plant populations across the Indian Himalayas, which is mainly attributed to over-exploitation of these important species and habitat degradation. Though the local people deserve credit for sustaining village forests for centuries, further loss of medicinal plants at these elevations should be discouraged. There is a need to generate awareness in society for both *in situ* and *ex situ* conservation of forests across the altitudinal gradients in order to maintain the viable populations of medicinally important species. Maintaining good population density as well as diversity of medicinal plants may diffuse the severity of anthropogenic pressures. The knowledge on distribution and density of a species may help design and redesign forest management practices.

Since the availability of a species in the study area is determined by elevation and forest types, there is a need to recognize areas having high density of medicinal plants within each forest type along the altitudinal gradient. These high density medicinal plant areas may be conserved for posterity by declaring them as medicinal plant conservation areas. At the same time, areas having low medicinal plant density may be brought under medicinal plant development areas, where resource augmentation practices may be implemented by involving local communities. In case of medicinal plant management, the managers cannot adopt simple protection measures as guided in the protected areas because medicinal plants are an important health care commodity and are required on an urgent basis. Involving local communities in medicinal plant protection and at the same time providing them benefits by augmenting medicinal plant resources may be a step further in conservation of medicinal plants.


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