Geospatial modelling techniques for rapid assessment of phytodiversity at landscape level in western Himalayas, Himachal Pradesh

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The mountainous state of Himachal Pradesh is known for its vast natural wealth, including forests, alpine meadows, rivers and valleys endowed with a rich array of life forms. However, this biodiversity hot spot is under great peril owing to human-induced disturbance factors. The findings on spatial representation of the habitat at a scale which can be used for conservation planning and rehabilitation are lacking. In this study IRS-1D, LISS-III sensor data have been used to assess the vegetation coupling with RS and GIS techniques in the state. This communication presents an approach for rapid assessment of biodiversity at landscape level using satellite remote sensing, phytosociological data and knowledge base in geospatial model. The geospatial analyses at the landscape level reveal that most of the fertile valleys of the region are occupied by the human activities and possess very low bio-richness. Inverse relationship has been observed with disturbance at landscape level *vis-à-vis* phytodiversity or richness of the vegetation type/habitat.

THERE is increasing awareness that biodiversity is not only intimately connected with long-term health and vigour of the biosphere, but is also a regulator of ecosystem functioning. The conventional species-level approach for biodiversity management has major limitations. The understanding of the priorities of biodiversity conservation and management has resulted in a policy shift from conservation of single species to habitats through interactive network of species at landscape level[1,2]. Microclimatic conditions are manifested in the form of four micro-endemic centres among 26 in India[3]. The Western Himalayan region has 12 out of the 71 genera endemic to the Himalaya. The Himalaya has more than five micro-endemic centres. The Himalayan ranges are among the youngest hills in the world, are active as well as fragile, and are facing threat from mankind in the name of development. Because of increased anthropogenic activities, as a result of population explosion and change in land use practices, the natural landscape has been modified resulting in fragmentation of forests with poor species composition[4,5]. The resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape and arrangement. Fragmentation of ecological units has been well-documented at landscape level using patch size, shape, abundance and forest matrix characteristics[6–10]. Ecosystem degradation and patch characteristics are associated with degree of spatial fragmentation[11–13]. Changes in landscape patterns through fragmentation or aggregation of natural habitats can alter patterns of abundance for single species and entire communities[14]. Understanding landscape spatial pattern is important since it contains all levels of biological hierarchy, from ecosystems to species and genes, which are targetted for biodiversity conservation.

Fine resolution remote sensing technology is being widely used the world over for quick assessment of earth resources. Being cost-effective and repetitive in nature with synoptic coverage technology, it has endless application potentials. Coarse resolution sensor data (WiFS) were used by various workers to assess the vegetation, but such data have limitations to discriminate the vegetation types at a finer level[15,16]. In this communication, vegetation-type map derived from IRS-1D, LISS-III fine resolution sensor data has been analysed for discriminating various vegetation types of the region. Vegetation-type map is the prime input for landscape ecological analysis of the forest ecosystem. Geographic Information System (GIS) is used to derive landscape indices such as fragmentation, porosity, patchiness, patch density, interspersion and juxtaposition, which depict landscape characteristics.

Himachal Pradesh (HP) in the western Himalayan range extends from the perpetual snow-covered mountains separating it from Jammu and Kashmir, and China in the north to Punjab Shiwalik ranges in the southwest and Uttaranchal in the southeast. Its hilly terrain system known for natural wealth, forests, meadows, rivers and steep valleys is enriched with rich cultural heritage. The majestic array of perpetual lofty snow peaks presents a breathtaking panoramic view. The state is known for its forests and their floral and faunal diversity. Among the 45,000 species of plants found in the country as many as 3295 species (7.3%) are reported in the state[17]. In HP, there are 30 wildlife sanctuaries, two national parks and three game reserves covering an area of 5940 km^2 (ref. 17).

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Study area

HP has a mountainous landscape with altitudes ranging from 350 to 6975 m above mean sea level. It is located between lat 30°22′ 40″ N–33°12′ 20″ N and long 75° 45′ 55″ E–79° 04′ 20″ E (Figure 1). It has a deeply dissected topography, complex geological structure and a rich temperate flora in the high altitudes. Physiographically, the state is divided into five zones, viz. (i) wet sub-temperate zone, (ii) humid sub-temperate zone, (iii) dry temperate-alpine high lands, (iv) humid subtropical zone, and (v) sub-humid subtropical zone. The average annual rainfall in the state is about 160 cm. The climate varies from warm and humid in the valley areas to freezing cold in the higher altitudes.

Material

Digital data of ten IRS 1D, LISS-III satellite scenes have been used for land-cover and land-use classification of the area. Survey of India (SOI) maps on 1 : 250,000 scale have been suitably referred. Relevant literature on flora has also been consulted[18–20]. Analyses were carried out in Octane machine (IRIX OS) using ARC/INFO, ERDAS Imagine, Bio-CAP customized package[21] (Figure 2).

Method

IRS-1D, LISS-III satellite remote sensing data were used for deriving vegetation cover-type map. The vegetation types thus derived were converted to represent the habitats and their spatial association. This extent of vegetation types is largely controlled by physiography, altitude and biogeography. The spatial organization of patches has been evaluated using landscape ecological principles[22]. Important landscape parameters used for landscape analysis are fragmentation, porosity, juxtaposition, patchiness and interspersion. Proximity of the habitat to a road or village determines human impact in the region. Required spatial information was integrated to determine disturbance regime. Spatial representation of biodiversity characterization at landscape level has been made by integrating important key attributes derived from the vegetation type-map, terrain complexity, disturbance regimes and phytosociological data. The methodology (geospatial model) used for biodiversity assessment at landscape level has been explained in Figure 2 (ref. 23).

Vegetation cover-type mapping

IRS-1D LISS-III data (March and November 2001) were used to prepare vegetation cover-type map. A total of ten scenes cover the whole state. Each scene was rectified with respect to 1 : 50,000 scale using ground-control points. A second-order transformation was used for rectification. Average root mean square error within one pixel was maintained while preparing the transformation model. Lambert Conformal Conic (LCC) projection was used during rectification of the image. Each rectified scene was subjected to radiometric correction before mosaicing it to a single image. Scene-wise classification has been carried out. Major vegetation types, deodar forest, mixed conifer forest, chir pine forest, temperate and alpine

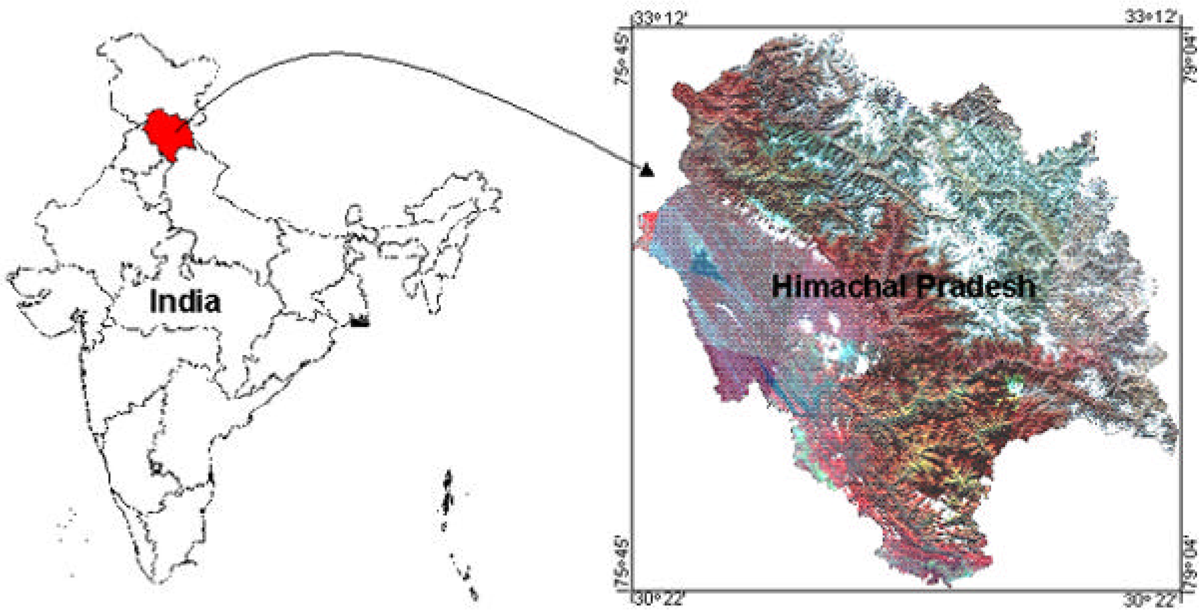

Figure 1. Location of the study area.

meadows were extracted by supervised classification method. Training sites were selected and processed, and features with high classification accuracy were extracted. Using binary image, the remaining area was extracted and put to unsupervised classification. Both unsupervised and supervised classification approaches in isolation could not yield satisfactory results. Hence the approaches were combined in hierarchical pattern to extract the remaining classes. By using these approaches vegetation classes of moist deciduous, dry deciduous, oak, *Betula/ Rhododendron*, Sal, etc. were extracted. Certain refinements were still necessary taking into account the contextual information collected from ground truth to delineate intermixing tonal characterisitics of the temperate vegetation types such as *Ephedra*, *Hippophae*, juniper, etc. Finally independent classified scenes were merged together to generate vegetation map for the entire area. Classified vegetation types have been compared with classification scheme of Champion and Seth[24] as represented in Table 1.

Phytodiversity analysis

Well-distributed samples are taken for information on species occurrence. Sampling intensity of 0.01% of natural vegetation has been found. Higher sample intensity is adopted (than recommended)[21] in view of variability in the area. Stratified random sampling approach was followed and number of sample points was distributed to its probability proportional to size. Classified vegetation cover-type has been used for finding sample size. Nested-plot technique[25] was used to optimize plot size and collect phytosociological data pertaining to trees, shrubs and herbs in a systematic way. Plot size was established on the basis of species area curve; however to keep the units

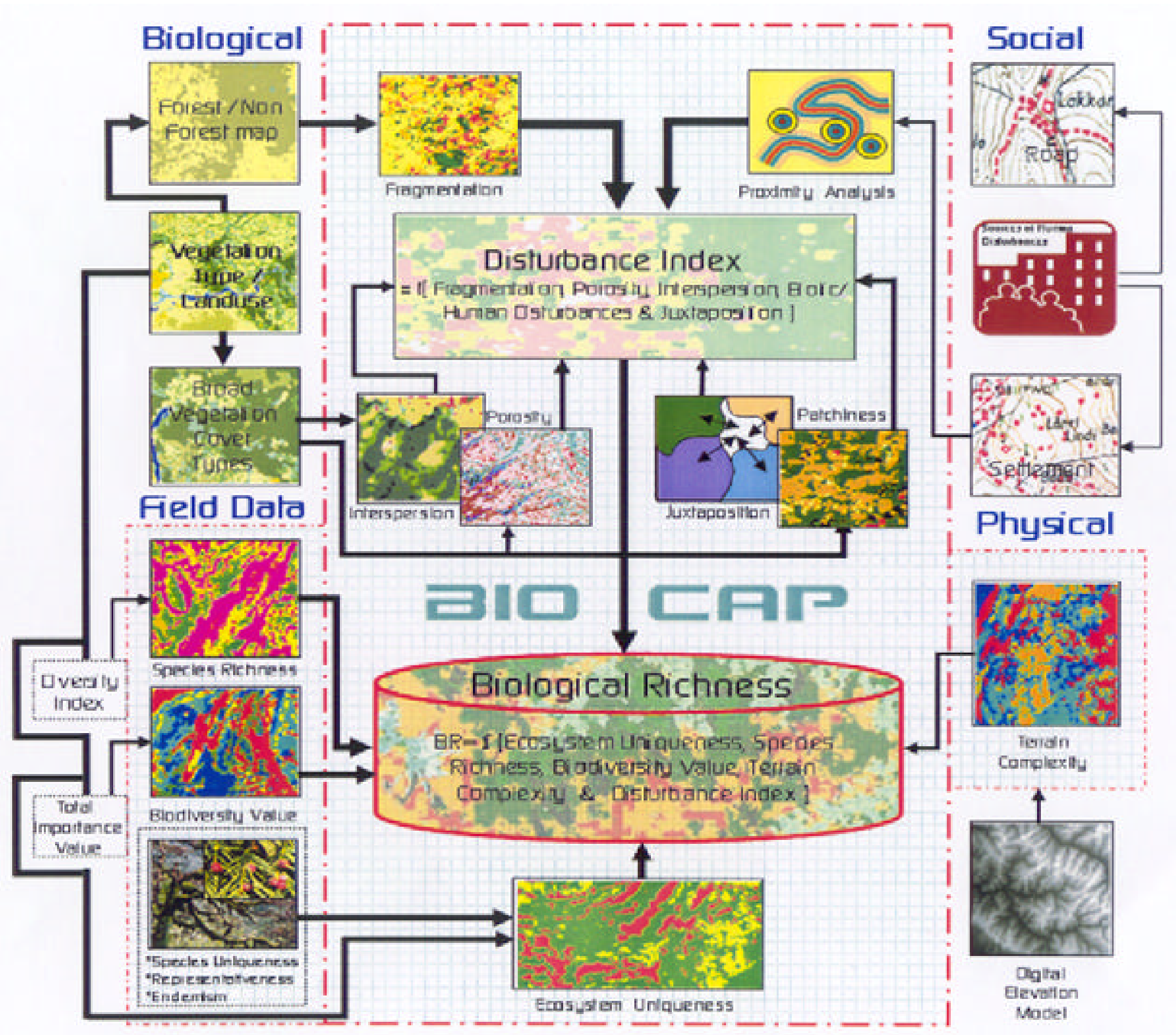

Figure 2. Schematic representation of geospatial model for biological richness mapping at landscape level (adapted from ref. 23).

uniform, quadrats were laid according to Roy *et al*.[21]. Sampling for trees was carried out using quadrats of 20 m × 20 m in size. Single quadrats each 10 m × 10 m in size were used for shrub and seedling layer within each 20 m × 20m size quadrat. For herbaceous layer, the quadrat size was restricted to 1 m × 1 m. Phytosociological analysis was carried out to determine species richness, economic and ecological importance. Detailed field inventory information is given in Table 2.

Economic valuation of biodiversity. Economically important plants are the species which have social and economic value. Different economic values can be assigned to different usage of plants. Importance value can be derived based on primary uses like forage, medicinal applications, human food, fuel wood, timber, charcoal, etc. and secondary direct benefits like production of oil, fibre, mat-making, ropes, etc. A scale of 0–10 points for each use was assigned based on the available literature[18–20] as well as field information collected from local people to calculate the Total Importance Value (TIV)[26] (Table 3).

Species richness (Shannon–Wiener Index). Species richness can be described as the number of species in a sample or habitat per unit area. The simplest measure of species diversity (H') is based on the total number of

Table 1. Vegetation classes compared with classification of Champion and Seth

Satellite-based vegetation cover type	Vegetation type according to classification by Champion and Seth
Alpine meadow	Alpine pastures (15/C_3)
Alpine scrub	Dry alpine scrub (16/C_1), Deciduous subalpine scrub (14/1S_2), Dwarf *Rhododendron* scrub (15/C_2/E_1)
Betula/Rhododendron	West Himalayan subalpine birch/fir forest (14/C_{1a})
Chilgoza	Neoza pine forest (13/C_{2a}), Dry broadleaved and coniferous (13/C_1)
Chir pine	Himalayan subtropical pine forest (9/C_1)
Deodar	Moist deodar forest (12/C_{1c})
Dry deciduous	Northern dry mixed deciduous forest (5B/C_2), Dry bamboo brakes (5/E_9)
Ephedra	Dry alpine scrub (16/C_1)
Hippophae	*Hippophae–Myricaria* scrub (13/1S_1), *Hippophae–Myricaria* brakes (14/1S_1)
Juniper	West Himalayan dry Juniper forest (13/C_5), Dwarf juniper scrub (16/E_1)
Blue pine	Low level blue pine forest (12/2S_1), West Himalayan high-level dry blue pine forest (13/C_4)
Mixed conifer	Upper west Himalayan temperate forest (12/C_2), West Himalayan upper oak-fir forest (12/C_{2b})
Moist deciduous	Khair-sissu forest (5/1S_2)
Oak	Ban oak forest (12/C_{1a}), Moru oak forest (12/C_{1b}), Oak scrub (12/DS_1), Kharsu oak forest (12/C_{2a})
Riverine	Alder forest (12/1S_1), Khair-sissu forest (5/1S_2)
Sal	Dry Siwalik sal forest (5B/C_{1a})
Scrub	Dry deciduous scrub (5/DS_1), Subtropical *Euphorbia* scrub (9/C1/DS_2), Subtropical *Euphorbia* scrub (DS_2)
Temperate broad-leaved	Alder forest (12/1S_1)
Temperate grassland	Himalayan temperate pastures (12/DS_3)
Temperate scrub	Himalayan subtropical scrub (DS_1), Dry temperate scrub (13C_2/DS_2)

Table 2. Phytodiversity analysis of vegetation of Himachal Pradesh

Vegetation type	No. of plots	Family	Genus	Number of species in each habit					Total
				Trees	Shrubs	Herbs	Climbers	Epiphytes	
Alpine meadow	145	43	98	0	2	143	–	–	145
Alpine scrub	204	41	114	0	46	175	–	–	221
Betula/Rhododendron	11	54	104	18	24	112	–	–	154
Chilgoza	8	17	34	8	8	46	–	–	62
Chir pine	39	23	31	35	63	132	–	–	230
Deodar	31	66	144	42	51	186	6	2	287
Dry deciduous	25	61	155	27	48	95	2	–	172
Ephedra	10	9	10	–	6	6	–	–	12
Hippophae	19	35	68	–	14	81	–	–	95
Juniper	9	28	55	6	12	50	–	–	68
Blue pine	19	63	137	16	44	148	2	3	213
Mixed conifer	52	88	235	48	77	306	7	2	440
Moist deciduous	36	80	221	58	73	183	13	2	329
Oak	38	75	199	33	61	195	–	9	298
Riverine	9	30	73	11	15	85	–	–	111
Sal	6	24	58	9	22	41	–	–	72
Scrub	17	53	94	–	60	91	5	–	156
Temperate broad-leaved	36	86	225	50	58	283	2	–	393
Temperate grassland	59	30	98	–	–	170	–	–	170
Temperate scrub	62	75	200	7	79	282	1	1	370

species and the total number of individuals in the sample or habitat. Greater the index value, higher the species richness (Table 3). The index represents the average degree of uncertainty in predicting the particular species an individual chosen at random from a sample will belong[27].

Ecological importance. Ecological importance with respect to species uniqueness in terms of rare, endangered, threatened, endemic was considered for establishing ecosystem uniqueness. The species recorded during the field data collection were screened for their uniqueness with the help of the *Red Data Book* and other available literature and accordingly, proportional weights were given to them. The weights of the number of species of IUCN categories present in various forest types were added to derive a relational weight. The weights obtained for various forest types were fed as an input to simulate the biological richness index.

Results and discussion

Estimated forest cover of the state is 13880 km^2, constituting 24.93% of the total geographical area of the region. This estimate was 1.4% more than that by Forest Survey of India (FSI). This may be a result of different classification methods followed in each case and also transformation of 1 : 50,000 scale assessment to 1 : 250,000

Table 3. Vegetation type-wise Shannon–Wiener index (H') and Total Importance Value (TIV)

Vegetation type	Species richness (H')	TIV
Alpine meadow	5.41	124
Alpine scrub	6.55	202
Blue pine	4.02	637
Betula/Rhododendron	4.34	574
Chilgoza	0.40	521
Chir pine	5.35	198
Deodar	7.64	775
Dry deciduous	7.13	955
Ephedra	0.80	85
Hippophae	1.72	310
Juniper	0.73	184
Mixed conifer	8.15	1023
Moist deciduous	6.84	1155
Oak	5.78	991
Riverine	2.17	147
Sal	2.07	421
Scrub	1.56	743
Temperate broadleaved	7.52	1045
Temperate grassland	4.32	287
Temperate scrub	7.25	956

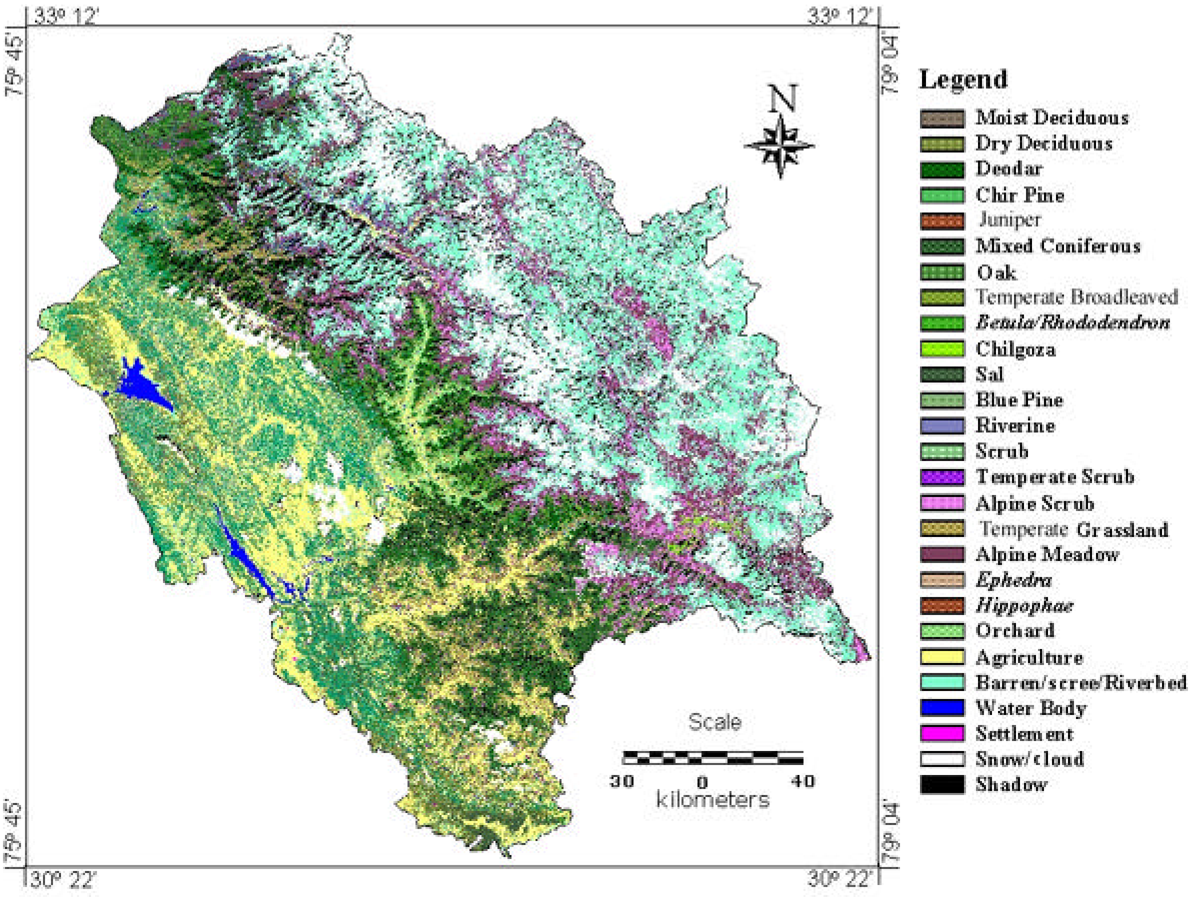

Figure 3. Land-use/land-cover type map of Himachal Pradesh.

scale by FSI[28]. Vegetation pattern of HP varies from dry scrub at lower altitudes to alpine meadows at higher altitudes. Between these two extremes distinct vegetation zones of dry deciduous forest, moist deciduous forest, pine, oak, deodar, mixed coniferous and temperate broad-leaved forests are found. A total of 20 vegetation types were identified (Figure 3, Table 4). Distribution pattern of these forests follows regular altitudinal stratification, except where micro-climatic changes occur due to aspect, slope and edaphic changes breaking the continuity. Roy[29] also observed this type of altitudinal control of vegetation in eastern Himalayas.

Siwalik hills in HP is dominated by dry deciduous forest with inter-mixing of scrub vegetation. Moist deciduous forest in fragmented patches was observed up to an elevation of 1700 m usually on northern aspects, due to higher moisture availability. Drier vegetation of chir pine and scrub forest was found mostly in southern and southwestern slopes, but chir pine forest is restricted to an elevation of 800 to 1500 m. Dry scrub vegetation distribution was found to be related to edaphic factors, notably dry rocky ridges, and in places where biotic pressure is high in terms of grazing and browsing by domestic herds of cattle and goats. Gregarious formations of deodar (*Cedrus deodar* Roxb.) and oak (*Quercus* species) forests were observed in relatively higher altitudes

Table 4. Area under different land-cover/land-use classes in the region

Land-use/land-cover class	Area in km^2	Percentage
Alpine meadow	5346.21	9.6
Alpine scrub	2086.92	3.8
Betula/Rhododendron	455.09	0.8
Chilgoza	76.98	0.1
Chir pine	2005.52	3.6
Blue pine	2193.6	3.9
Deodar	2153.35	3.9
Dry deciduous	26.78	0.1
Ephedra	81.97	0.2
Hippophae	258.43	0.5
Juniper	208.41	0.4
Mixed conifer	3226.72	5.8
Moist deciduous	1573.62	2.8
Oak	879.38	1.6
Riverine	24.66	0.04
Sal	306.97	0.55
Scrub	2152.55	3.87
Temperate broadleaved	408.83	0.73
Temperate grassland	2154.36	3.87
Temperate scrub	321.64	0.58
Orchard	542.77	0.97
Agriculture	7924.46	14.2
Barren	10097.78	18.1
Water	386.43	0.69
Settlement	14.45	0.03
Snow	6160.76	11.1
Cloud	659.21	1.18
Shadow	3945.54	7.09
Total	55673.42	100

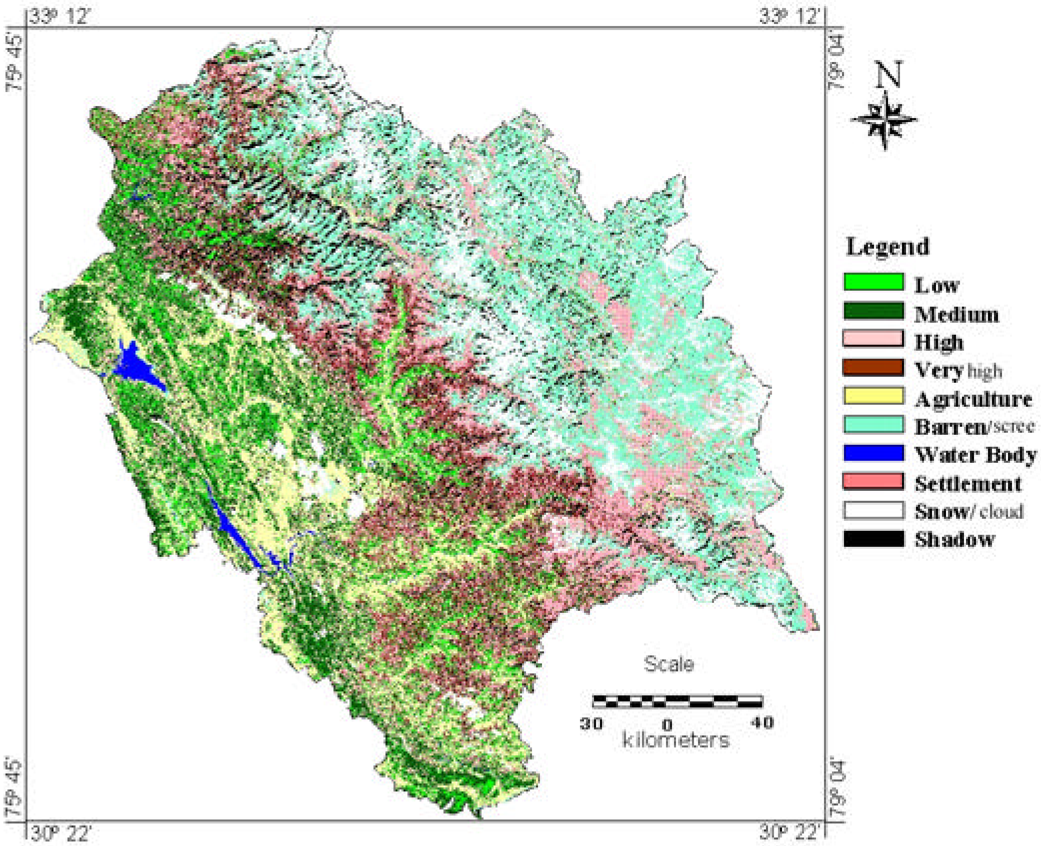

Figure 4. Biological richness map of Himachal Pradesh.

between 1500 and 2500 m. Deodar and oak distributions of these two communities usually occupied the cooler aspects in most of the area. Grassland communities were found in dry and warmer southern slopes at similar elevations. These communities divide at the ridge line. Mixed coniferous forests with consociations of deodar, fir and spruce were delineated just above the oak deodar belt between 2500 and 3200 m altitude.

Temperate broadleaved forest occupied the higher portion of the temperate belt, particularly in the outer ranges of the northern aspects. Degradation due to overgrazing has turned these forests into temperate grasslands having a variety of grasses and herbaceous flora. Forests of birch (*Betula utilis* D. Don), and rhododendron (*Rhododendron* species) with intermixing of fir (*Abies pindrow* Royle) forests were found in the subalpine zone. The uppermost portion of these forest forms the tree line in the eastern part of the state. On the other hand, kharsu oak (*Quercus semicarpifolia* Sm.) forests with stunted growth forms the tree line in most of the alpine zones at the average altitude of 3800 m. Alpine meadows bearing mostly grasses and mesophytic herbs, extended over vast tracks just above the timberline. Alpine scrubs, usually with stunted growth and often with xerophytic elements are found in the dry zones, chiefly on the northern and northeastern aspects broken by the meadows. Pure and relatively bigger patches of juniper scrub were demarcated and more frequently in very dry sites exposed to intense isolation. A more or less pure thicket of *Hippophae* scrub was observed along the river banks and riverbeds in the subalpine and alpine zones between 2500 m at the northern dry belts and 4200 m in the eastern part of the state. Similarly, fairly bigger patches of *Ephedra* scrub were delineated in arid cold deserts, usually in xerophytic formations.

Mixed coniferous forest shows highest diversity (8.15) with total number of 440 species followed by deodar (7.64), temperate broadleaved (7.52), temperate scrub (7.25) and dry deciduous forest (7.13) with total of 287, 393, 370 and 172 species respectively. These are followed by moist deciduous, alpine scrub, oak, alpine meadow, chir pine, *Betula/Rhododendron*, temperate grassland and moist deciduous in decreasing order. Table 4 provides detailed information regarding biodiversity.

The forests of HP are rich in their biodiversity especially in transitional zones between temperate and alpine (Figure 4). Alpine meadow and mixed conifer forest showed high degree of richness followed by alpine scrub, scrub, deodar and moist deciduous forest communities. The reason could be that these areas experience least disturbance because of very low population density and inaccessibility. It is also observed that disturbance affects biological richness. Relatively more biologically rich area was observed where the area under disturbance possesses very low. However, area under biological richness decreased with increase in disturbance (Figure 5).

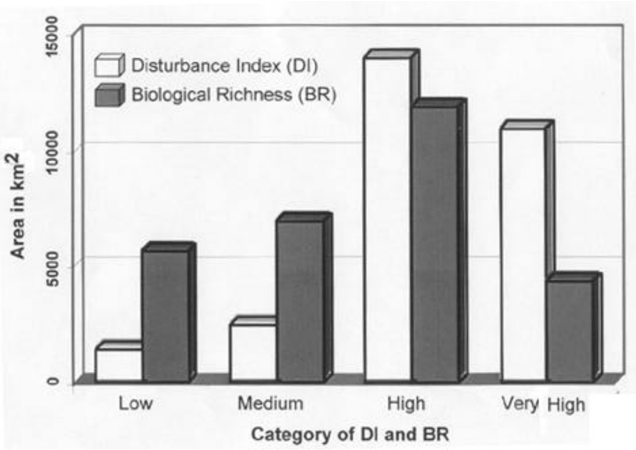

Figure 5. Relationship between disturbance index and biological richness.

Conclusions

The study has identified areas with various levels of biological richness. It is hoped that these results and maps will be useful in land-use zonaton and planning for sustainable use of natural resources. It may be said that only with this level of understanding of biodiversity can a long-term success of conservation policies be assured. Disturbance is one of the major factors for biodiversity loss. Biodiversity of forest patches depends on the existing environmental conditions. The analysis done in GIS domain using remotely sensed data and information from phytogeographical analysis revealed that majority of the area is highly disturbed, and therefore it is a matter of great concern for biodiversity conservation. The approach of this study is unique due to representation of the results in spatial form that may help in baseline study, planning of plant species inventory, and act as a prime input for species habitat evaluation, etc.

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