Assessment of biological richness in different altitudinal zones in the Eastern Himalayas, Arunachal Pradesh, India

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This article evaluates an approach for biological richness assessment at landscape level using satellite remote sensing, phytosociological data and knowledge base in a GIS domain at a test site in the Eastern Himalayan region. An attempt is made to establish the relationship existing between biological richness and biotic disturbances across an altitudinal gradient, divided into six zones based on different vegetation types. Biological richness was determined as a function of ecosystem uniqueness, species diversity, biodiversity value, terrain complexity and disturbance index. Satellite images of IRS 1C/1D LISS III are used to stratify different vegetation types following a hybrid approach supplemented with biogeographic and altitude zone maps. The number of economically important species, medicinal species and endemic species decreases with altitude. High level of disturbance was observed across settlements and road networks and the areas having simpler and easily accessible terrains. A declining trend in species richness and plant endemism is noticed with increase in altitude. Habitats with low disturbance, highly complex terrain, high degree of species richness, plant endemism and species uniqueness show high level of biological richness. In general, the disturbance decreased with increase in altitude, whereas biological richness shows a hump-shaped pattern for Arunachal Pradesh. It was observed that high biological richness and high disturbance occurred in lower altitudes, whereas high-altitude areas showed low biological richness and low level of disturbance. The study demonstrates integration of remote sensing and GIS for landscape ecological modelling and thereby contributes to the understanding of biodiversity distribution in the Eastern Himalayas, Arunachal Pradesh.

THE understanding of the priorities of biodiversity conservation and management has resulted in a shift in approach from conservation of a single species to habitats through interactive network of species at landscape level[1,2]. Landscape ecology seeks to understand the ecological functions of larger areas and hypothesizes that spatial ecosystems, habitats or communities have ecological implications in biological richness distribution[3–5]. Several workers have studied the patterns of species richness in biogeographical, ecological or habitat space[6–8]. Studies have dealt with the relationships between richness patterns and various ecological, geographical or other factors[9]. Anthropogenic influence on the landscape modifies landscape, ecosystems, communities and population structures, the physical environment and the availability of resources[10]. Severe disturbances or lack of disturbance generally has a depressing effect on biodiversity[10]. The accuracy and validity of modelling geographical patterns of species richness are critical factors in distinguishing and understanding the so-called hotspots of biodiversity[11]. Fuller *et al.*[12] combined field surveys of plants and animals with satellite remote sensing of broad vegetation types to map biodiversity and thereby helped plan conservation in Sango Bay area, Uganda. Debinski *et al.*[13] have used remotely sensed data and Geographic Information System (GIS) to categorize habitats and have determined the relationship between remotely sensed habitat categorizations and species distribution patterns. A number of studies have been carried out in India to establish the relationship between disturbance and biological richness of landscape elements[14–16].

This article evaluates an approach for biological richness assessment at landscape level using satellite remote sensing, phytosociological data and knowledge base in geospatial domain[16] at a test site in the Eastern Himalayas. Satellite imagery provides information on vegetation cover and its attributes. GIS is used to build a comprehensive database on physical, biological and environmental parameters which govern the spatial distribution of biodiversity. Landscape ecological analysis unravels the impact of human intervention, spatial pattern and organization of the habitats. This approach allows combining field data, ancillary data and information derived from satellite imagery for defining conservation strategies and prioritizing sites for bioprospecting.

Uniqueness of the study site

The Eastern Himalayas are located on the confluence zone of the Indo-Malayan, Afro-tropic and Indo-Chinese biogeographical realms. The Himalayan and Peninsular Indian elements had formed when the peninsular plate struck against the Asian land mass after it broke off from Gond-

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wanaland[17]. This region is one among the 25 hotspots of the world. Hooker[18] attributed the floristic diversity of the region to the immigration of plants from different bordering countries, notably Chinese and Malayan on the east and south, Oriental, European and African on the west and Tibetan and Siberian on the north. The humid conditions have resulted in speciation of several genera, thus adding to high endemicity of the flora[19]. In India's sector of the Eastern Himalayas, there are about 5800 plant species, of which roughly 2000 (36%) are endemic[20]. In addition, the Eastern Himalayas is an important Vavilovian centre of diversity and origin of important cultivated crop species and some domesticated animals[21]. The Eastern Himalayas is one among the 150 important botanical sites identified for conservation action by the World Conservation Monitoring Center[22]. The region is recognized as a refugium of flowering plants and is an active centre of organic evolution[23]. Takhtajan[24] has regarded it as the cradle of flowering plants. Arunachal Pradesh comprises eleven districts (Figure 1) and forms a part of the Eastern Himalayas. It is a vast repository of plant resources with both ecological and economic importance. There is linking of three different mountain ranges with diverse histories of evolution[17]. The distribution of various forest types follows altitudinal zonation. They accommodate numerous primitive angiosperm families, i.e. Magnoliaceae, Degeneriaceae, Himantandraceae, Eupomatiaceae, Winteraceae, Trochodendraceae, Tetracentraceae, and Lardizalbalaceae and genera, i.e. *Alnus*, *Aspidocarya*, *Betula*, *Euptelea*, *Exbucklandia*, *Haematocarpus*, *Holboellia*, *Houttuynia*, *Magnolia*, *Mangelietia*, *Pycnarrhena* and *Tetracentron*. The resource value of this region spans from timber to non-timber category, medicinal, aromatic to food and industrial gene pools and other economically important sectors. The flora of Arunachal Pradesh comprises well over 6000 species of flowering plants, of which nearly 30–40% is endemic[25]. However, the region is exposed to severe alterations in land use due to shifting cultivation (Jhumming), indiscriminate felling and illegal deforestation[26]. These coupled with socio-economic changes have caused loss of natural habitats and complex assemblies of species, accelerating the process of degradation.

Assessing biological richness – the approach followed

Biological richness at landscape level was determined as a function of ecosystem uniqueness (EU), species diversity (H′), biodiversity value (BD), terrain complexity and disturbance index (Figure 2). Satellite images of IRS 1C/1D LISS III (Table 1) were used to stratify different vegetation types following an integrated approach[26] (i.e. combination of unsupervised classification, supervised classification and introduction of human knowledge from field experience) supported by biogeographic zone[27] and altitude zone[28] maps. Wherever necessary, field knowledge was used to delineate the locale-specific types of ecological significance (Figure 3). The advantage of this approach is that it provides detailed information on community, gregarious formations and man-made forests for further analysis. Field visits were made to collect information on cover type, locality, aspect, slope, geographical location using GPS, signs of disturbance and altitude. Stratified random sampling with probability proportion to the size was adopted for analysing vegetation composition. A total of 405 sample plots were laid, accounting for 0.002 to 0.005% of various vegetation types. Within each nested sample plot, measurements on all trees (20 × 20 m), shrubs (10 × 10 m) and herbs (1 × 1 m) were enumerated, and ancillary information such as uniqueness of species, various life forms and economic uses was noted. Size of the quadrat and number of the quadrats laid were determined through species–area

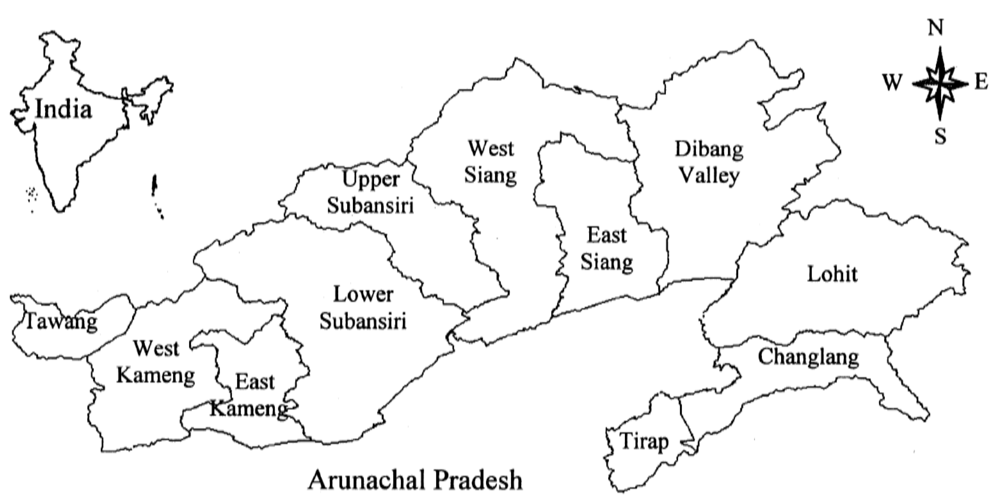

Figure 1. Location map of study site. Arunachal Pradesh comprises eleven districts.

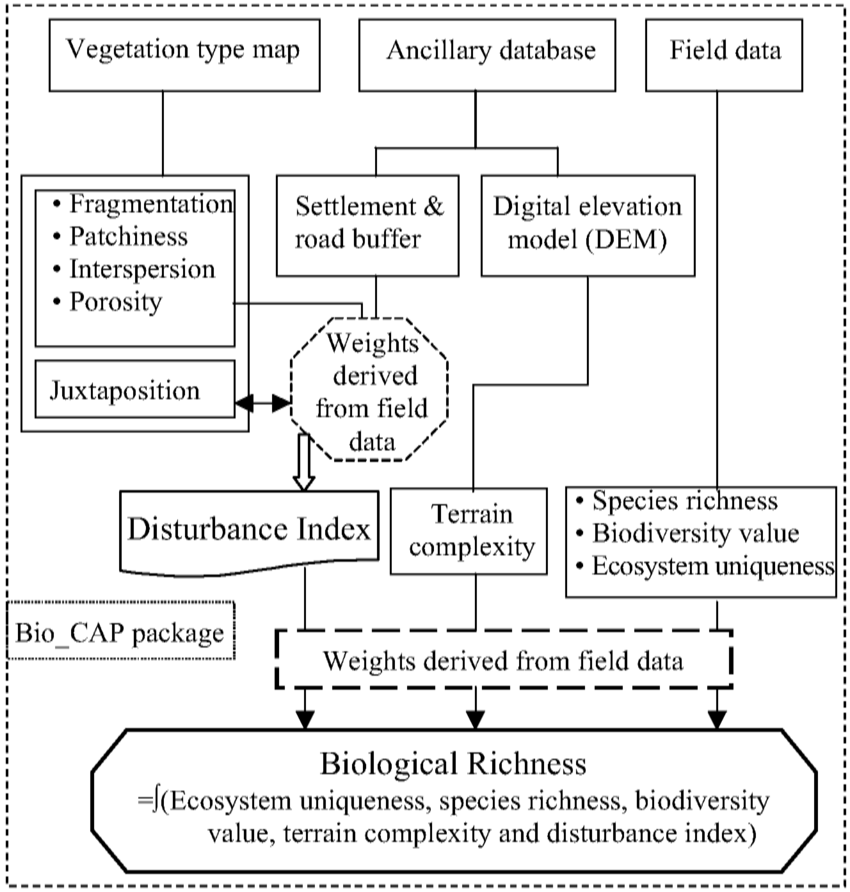

Figure 2. Flow diagram depicting methodology for disturbance index and biological richness assessment. This involves landscape analysis using satellite remote sensing and integration of phytosociological data and knowledge base in GIS domain with a customized package Bio_CAP.

Table 1. Description of LISS-III images used in the study

Satellite	Path/row	Period-I	Period-II
IRS 1C	110/50	December 1997	March 1998
IRS 1C	111/51	December 1996	March 1998
IRS 1C	111/52	December 1996	March 1998
IRS 1C	112/50	January 1997	March 1998
IRS 1C	112/51	January 1997	March 1998
IRS 1C	112/52	January 1997	March 1998
IRS 1C	112/53	January 1997	March 1998
IRS 1D	113/50	January 1999	March 1998
IRS 1D	113/51	January 1999	March 1998
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IRS 1D	113/53	January 1999	March 1998
IRS 1D	114/50	February 1999	March 1999
IRS 1D	114/51	February 1999	March 1999
IRS 1D	114/52	January 1998	March 1999
IRS 1D	114/53	February 1999	March 1999
IRS 1D	115/50	February 1999	April 1998
IRS 1C	115/51	February 1999	April 1998
IRS 1D	115/52	February 1999	April 1998
IRS 1D	115/53	February 1999	April 1998
IRS 1D	116/51	February 1999	April 1998
IRS 1D	116/52	February 1999	April 1998

curve[29]. The importance value index and, in turn, species diversity (viz. Shannon–Wiener index) were calculated for each stratum.

Bio_CAP, a geospatial semi-expert package was developed using GIS package (Arc/Info), Image Processing (ERDAS) and C/C^{++} for biological richness assessment[30]. Landscape ecological indicators (i.e. fragmentation, patchiness, porosity, interspersion and juxtaposition) were calculated using Bio_CAP, wherein a user grid cell of $n \times n$, where $n = 500$ m was moved with the spatial data layer and a given criterion of deriving the number of patches within the grid cell. The iteration was repeated by moving the grid cell through the entire spatial layer. The output layer that contains the normalized data of the patches per cell was scaled between 0 and 10. Vegetation cover-type map was used as the input layer to derive fragmentation, patchiness, porosity, interspersion and juxtaposition for calculating the disturbance index. Field-derived information was assigned to vegetation-type map to derive EU, H′ and BD maps. At landscape level, disturbance is related to patch structure and spatial arrangement that determines

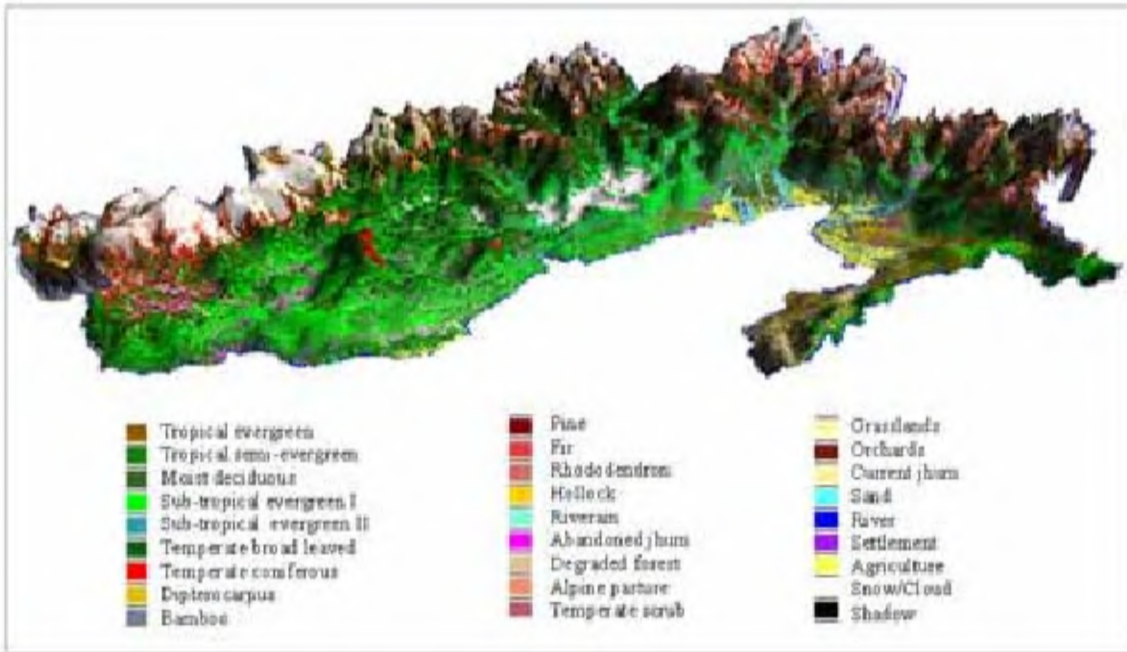

Figure 3. Vegetation type map of Arunachal Pradesh (draped over digital elevation model), derived by adopting a hybrid classification approach. A total of 21 vegetation and land cover classes were mapped.

the fate of patches and their size and duration. Disturbance is one of the main factors influencing the variation in species diversity[31]. Baseline details on roads and settlements were used to create a 2.5 km buffer (i.e. influence zone around the source of disturbance). Variable buffering with respect to radial distance from the point of disturbance was performed by imposing the condition that greater the distance less the weight is. Disturbance index (DI) was computed by adopting linear combination of defined parameters on the basis of probable weights (Figure 4).

$$\mathrm{DI} = \int \{\text{Fragmentation, patchiness, interspersion, porosity, biotic disturbance, buffer, juxtaposition}\}.$$

Ecological importance with respect to species uniqueness in terms of plant endemism was considered for establishing ecosystem uniqueness using field data. Each species was evaluated for its occurrence in the Eastern Himalayas[29,32–35] and accordingly, proportional weights were assigned to them[36]. The weights of the number of species present in different vegetation types were added to derive relational weights, which provided input to estimate the biological richness index. Species diversity, i.e. Shannon's index was calculated as the number of species in a sample or habitat per unit area[37]. This index is based on the total number of species and total number of individuals in the sample or habitat. Higher the value, greater the species richness. Economically important plants are the species which have social and economic value. Importance value was derived based on primary uses like forage, medicinal applications, human food, fuel wood, timber, charcoal, etc. A scale of 0–10 points for each use was assigned based on the available literature as well as field information collected from local people to calculate the biodiversity value[32–36]. Terrain complexity was derived using elevation information through digital elevation model[29,30]. Biological richness values were scaled to five qualitative grades (Figure 5).

$$\text{Biological richness} = \int \{\text{Ecosystem uniqueness, species diversity, biodiversity value, terrain complexity and disturbance index}\}.$$

Results and discussion

In general, it was observed that the number of species decreases with increase in altitude for Arunachal Pradesh. The number of economically important species, medicinal species and endemic species decreases with altitude (Table 2). This declining trend in species number with increase in elevation was found to be in accordance with the general altitudinal pattern of species distribution[6–8]. Biologically rich areas followed a hump-shaped curve, whereas the disturbance decreased gradually with increase in altitudinal zones (Figure 6).

A total of 21 vegetation and land cover classes were mapped (Figure 3). Correspondence using field-gathered GPS points for vegetation classes in two selected eco-regions showed 89.25 and 85.25% overall mapping accuracy[38,39];

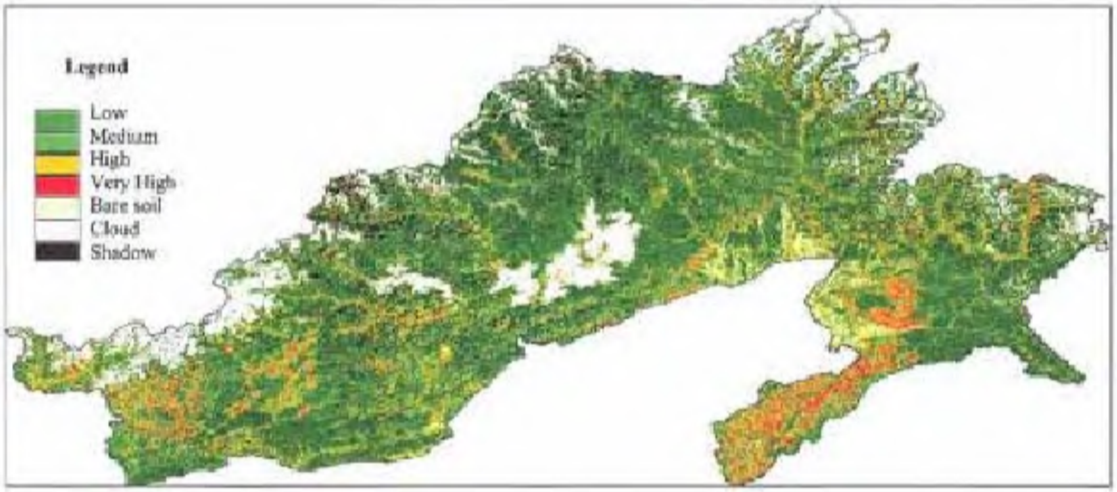

Figure 4. Disturbance index map of Arunachal Pradesh computed by linear combination of fragmentation, patchiness, porosity, interspersion, juxtaposition and biotic disturbance buffer. Disturbance is qualitatively scaled to four groups on the map.

Table 2. Species diversity and endemism are characteristics of altitude. Total number of economically and medicinally important species, endemic species, total number of families and five dominant families observed in six altitudinal zones corresponding to various vegetation types. (Total number of economically important plants includes medicinally important plants given in parenthesis.)

Vegetation zone[26,28]	No. of economic species	No. of medicinal species	No. of endemic species	Five dominant families
I Up to 900 m	537	291	107	Euphorbiaceae, Lauraceae, Meliaceae, Verbenaceae, Sterculiaceae
II 900–1800 m	373	205	77	Fagaceae, Pinaceae, Rosaceae, Saurauiaceae, Urticaceae
III 1800–2800 m	250	124	71	Fagaceae, Aceraceae, Poaceae, Rosaceae, Lauraceae
IV 2800–3500 m	65	41	15	Pinaceae, Ericaceae, Rosaceae, Ranunculaceae, Myrsinaceae
V 3500–4000 m	52	28	06	Ericaceae, Pinaceae, Ranunculaceae, Violaceae, Saxifragaceae
VI 4000–5500 m	19	13	03	Ericaceae, Pinaceae, Ranunculaceae, Crassulaceae, Rosaceae

this is well within the expectations from an operational product for a variety of applications[12,40]. The vegetation cover map offers the potential of identifying distribution of various ecosystems. Kaul and Haridasan[28] have tried to relate distribution of various forest types with altitudinal ranges in Arunachal Pradesh. They classified various forest types with respect to six altitudinal zones, viz. (I) tropical, (II) sub-tropical, (III) temperate broad-leaved, (IV) temperate coniferous, (V) sub-alpine and (VI) alpine (Table 2). Each vegetation zone has an intermixing ecotonal extent[26] of about 50 to 200 m. The disturbance index (DI) map shows four levels of disturbance scaled on qualitative basis (Figure 4). Low levels of fragmentation, patchiness, porosity, interspersion, high level of juxtaposition and increased distance from the sources of biotic disturbance characterized low disturbance areas in the DI map (Figure 4). Areas nearer to habitation were observed to have high levels of disturbance. Some reserved forests adjacent to habitations were under high level of disturbance. Most of the forest areas supplemented with complex terrain were seen to be under low and medium levels of disturbance (Figure 4). DI map shows highly disturbed areas in most of Tirap and lower reaches of Lohit districts, West Kameng and Lower Subansiri district across agriculture and shifting cultivation areas. Habitats with low disturbance, highly complex terrain and that are highly interactive and important are adjudged as biologically rich areas (Figure 5). The biological richness (BR) map of Arunachal Pradesh reveals that tropical forests which occur in Namdhapa National Park and border areas of Lower Subansiri, West Kameng, East Siang and Lohit district are rich. Alpine pastures and temperate conifer areas indicate high biological richness. Medium-richness areas form the largest part of the State and are spread throughout (Figure 5). Low biologically rich

Figure 5. Biological richness map of Arunachal Pradesh calculated as a function of ecosystem uniqueness, species diversity, biodiversity value, terrain complexity and disturbance index. Biological richness is scaled to four groups.

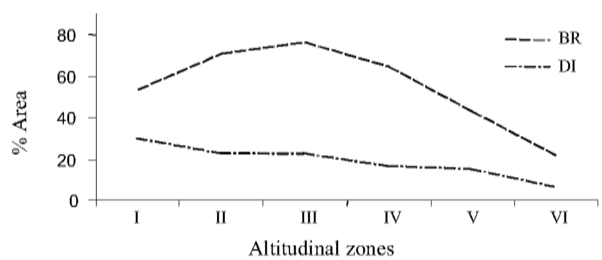

Figure 6. Relationship between disturbance index (DI) and biological richness (BR) across six altitudinal zones corresponding to different vegetation types. Biological richness depicts a hump-shaped curve, whereas disturbance index decreases more or less linearly with altitude. At higher altitudinal zones, both exhibit a declining trend.

areas are found scattered throughout the State on non-forest lands bordering agriculture and shifting cultivation patches. Alpine pastures and temperate coniferous areas also have high biological richness; moderately rich areas form the largest part in the State. Biologically rich areas followed a hump-shaped curve, whereas the disturbance decreased with increase in altitude across various vegetation zones (Figure 6). Biologically rich areas are those habitats where landscape ecological conditions are favourable for natural speciation and evolutionary process. The results of biological richness assessment support the hypothesis that though tropical forests are richer in diversity, they are also affected by disturbance. Relatively high biological richness was observed in low disturbance areas (Figure 5). Unclassified attributes like snow, cloud and shadows were shown on the vegetation type, disturbance index and biological richness maps. Major roads and drainage networks are overlaid on the BR map to provide easy locational clues.

Biological richness and disturbance index were calculated and plotted against altitudinal zones (Figure 6). Biological richness increases from zone-I and zone-II (corresponding to tropical and sub-tropical) with maxima at zone-III (corresponding to temperate broadleaved) and then decreases gradually up to zone-VI; whereas disturbance curve showed a gradual decrease from zone-I to zone-VI. Figure 6 explains the functional relationship between biological richness and disturbance along altitudinal gradient. The analysis also reveals that lower altitude areas have high biological richness, but are prone to high level of disturbance. Chandrashekhar *et al.*[41], in a study in one of the western Himalayan sites, observed that areas under 'high' biological richness decreased with increase in disturbance. The present study agrees with the above observation for zones I–III, but deviates for the higher altitudinal zones. For zones IV–VI, even though there is a decrease in disturbance, the biological richness decreased (Figure 6). The disturbance, which is dominantly anthropogenic in nature in zones I–III, could be beyond the resilience capacity of the constituent ecosystems, leading the transformation into stress and causing a decrease in biodiversity. In turn, the biotic disturbance in zones IV–VI seems to be well within the resilience capacity of the ecosystems, but the decrease in biological richness in these zones might be because of other environmental constraints.

Conclusion

Satellite remote sensing has enough potential to classify vegetation with substantial ground truthing for biodiversity analysis purpose (Figure 3). Vegetation analysis along altitudinal gradient provides important insights into the driving forces responsible for the evolution process (Table 2, Figures 3–5). The analysis of various landscape ecological parameters describes the degree of fragmentation, interspersion and juxtaposition among various habitat patches, which in combination with settlements and road networks rightly estimated various disturbance regimes for the State (Figure 4). Thus, it may undoubtedly concluded that some areas of Tirap, Changlang, Lohit, West and East Kameng, Tawang and undivided Lower Subansiri show very high and high levels of disturbance. The DI map reflects that the disturbance level is high in areas having low biotic interference. Inaccessible areas, where the terrain is more complex, are relatively free from disturbance. Such areas possess nearly undisturbed forests. The BR map reflects well the biodiversity status of the State (Figure 5). The lower tropical areas of West Kameng, East Kameng, Lower Subansiri, Lohit, Changlang and Tirap districts are found to be biologically rich in Arunachal Pradesh. Though disturbance decreases gradually with increased altitudinal zones, biological richness follows a hump-shaped pattern in the State (Figure 6). The study reveals that lower altitude areas pertaining to tropics and sub-tropics have high biological richness and high disturbance as well. The declining trend of species number with increase in elevation observed for Arunachal Pradesh is in accordance with the general altitudinal pattern of species distribution[8]. This altitudinal pattern of species distribution could be due to its location at the trijunction, dispersal across various barriers, speciation and mutation (Table 2). This property could also be attributed to more congenial conditions prevailing in the tropics and sub-tropics compared to the temperate and alpine zones[42].

The landscape perspective is fundamental to understanding the role of disturbance. Disturbance regimes vary across landscapes as a function of topography. Disturbance due to jhumming has produced heterogeneity in the State (Figure 4). At micro-scale, vegetation heterogeneity is dominated by slope, soil type and vegetation disturbance regimes. The DI map includes type of disturbance, size of patches disturbed and magnitude of disturbance (separated into measures of disturbance force or intensity and effects on the ecosystem or severity). Shortening of jhum cycle due to increasing population growth might have contributed to the disturbance severely. The BR map provides an index for conservation that can only be judged with a critical understanding of the whole spectrum of biodiversity attributes attached to it (Figure 5). The DI and BR maps may help plan and better manage possible nature reserves to identify and implement buffer zones and to define multi-use areas where predominantly traditional practice can continue. This study has also created an information base which would help design conservation schemes for long-term maintenance of biodiversity. The primary requirement to evolve such an approach (Figure 2) is (a) assessment of habitats, their quality and extent; (b) determination of disturbance regimes; (c) information on spatial distribution of biological richness; (d) determination of the optimum size of conservation areas, and (e) identification of a set of species sensitive to particular landscape function and structure. Instead of simply preserving the target species in isolation, the prioritization process for biodiversity conservation necessitates preserving species assemblies in biologically rich areas. The approach followed and various results presented would facilitate (i) rapid assessment for monitoring biodiversity loss and/or gain, (ii) assessing the nature of habitat and disturbance regimes, (iii) evolving species–habitat relationship, (iv) mapping biological richness and gap analysis and (v) prioritizing conservation and bioprospecting sites.

The relationship established for biological richness and disturbance with altitude would provide inputs for understanding the Eastern Himalayan ecosystems. Though biological richness has shown an increasing tendency till zone III, disturbance followed a decreasing altitudinal pattern (Figure 6). Further intensive research is necessitated to understand the inherent relationship existing between biological richness and disturbance. This study used only one parameter, i.e. altitude to establish the relationship. Many other parameters, if considered, would provide further insight into the understanding of biodiversity characteristics in Eastern Himalayas. Remote sensing and GIS technologies would continue to provide the basis for biodiversity assessment studies in future.

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