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RESEARCH ARTICLE

Assessment and Validation of Biological Richness at Landscape Level in part of the Himalayas and Indo-Burma *Hotspots* using Geospatial Modeling Approach

M. D. Behera · P.S. Roy

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Abstract Validation is a necessary step for model acceptance and is defined as a comparison of the model's predictions with real world to determine whether the model is suitable for its intended purpose. We have validated the biological richness index for three states generated in 'Biodiversity Characterization at Landscape Level' project under the aegis of Department of Biotechnology and Department of Space of the Government of India. Biological Richness (BR) index, described elsewhere as a cumulative property of ecological habitats and surroundings; was analyzed as an integrated 'three-tier modeling approach' of (i) utilization of geospatial tools, (ii) limited field survey and (iii) landscape analysis.

For validation, we categorized the field plots into 10-groups corresponding to 10-levels of BR using data splitting technique using their GPS-recorded positional information. In general, the number of tree, shrub and liana species and mean BA demonstrated a decreasing trend with lowering of BR for all three states falling under both the *hotspots*. However, the number of endemic species increased with decrease in BR levels for Meghalaya and Arunachal Pradesh; and decreased for the state of Assam. The study validates the BR index derived using geospatial modeling approach, thereby provides confidence in its acceptance for ecological conservation purposes.

M. D. Behera[1] (✉) • P.S. Roy[2]

[1]Centre for Oceans, Rivers, Atmosphere and Land Sciences (CORAL)
Indian Institute of Technology (IIT)
Khargpur-721302, W.B., India

[2]Indian Institute of Remote Sensing
NRSC-ISRO, Govt. of India
Dehradun-248001,Uttarakhand, India.

email : mdbehera@coral.iitkgp.ernet.in

Introduction

The understanding of the priorities of biodiversity conservation and management has resulted in a shift of approach from conservation of a single species to habitats through interactive network of species at landscape level (Orians, 1993). Vegetation types or ecological habitats possess spatial, physical, social, phytosociological, ecological and economical attributes (Behera *et al*., 2005), and the information content of vegetation can be measured using species diversity (Whittaker, 1977; Burton *et al*., 1992). Since the present day challenge is *insitu* conservation, it is required to identify and prioritise biological richness of habitats or ecosystems for conservation planning. BR has been regarded as a cumulative property of any ecological habitat and its surrounding environment and its appropriate assessment is possible only when maximum number of biodiversity surrogates are considered. Six biodiversity attributes (*i.e*., spatial, phytosociological, social, physical, economical and ecological) were linked together based on their relative importance to stratify the BR of forest vegetation in parts of Himalaya and Indo-Burma *Hotspots* (Anonymous, 2002). Satellite images are potentially used as a convenient tool to analyze landscape patterns since they provide a digital mosaic of the spatial arrangement of land covers (Coulson *et al*., 1990; Chuvieco, 1999; Behera, 2001). Ecological models have a vital role in the process of converting remote sensing data products into actual knowledge of species distribution and richness (Turner *et al*., 1993). Coupled with GIS and GPS, remote sensing is a powerful tool to describe the geographical characteristics of ecological systems, model prediction and validation (Farina, 1998; Behera *et al*., 2000). Inventory and assessment of existing levels and spatial pattern of biodiversity in various parts of the world are increasingly being done using various ecological modeling techniques (Noss *et al.,* 1995; Ricketts *et al.,* 1999; Anonymous, 2002). The most commonly used techniques of validation is the *test of hypothesis* that the regression line of observed versus predicted values passes through the origin with a slope of unity (Fielding and Bell, 1997). A number of useful statistics are available from regression analysis -R^2 indicates the degree of fit, significance of the quadratic term can be used as a test for curvature, and the fitted constants indicate any observed biases in the model. The parametric linear regression analysis of the observed *vs* predicted plots are the most useful general statistical methods (Mayer and Butler, 1993).

Landscape is the best spatial scale to assess the response of biodiversity across different groups of organisms as it can commensurate with the alternations caused by humans (Turner *et al.*, 1993). The landscape properties were analyzed using various quantitative indices (Baker and Cai, 1992) following geographic windows approach (Dillworth *et al*., 1994). The spatial arrangement of patches, their different quality, the juxtaposition and the proportion of different habitat types are elements that influence and modify the behavior of species populations and communities (Lidicker, 1995). Terrain plays an important role in maintaining species diversity by offering microhabitats. Endemism is the principal criterion for *hotspot* status determination because endemic species are entirely dependent on a single area for their survival and by virtue of their more restricted ranges, are often the most vulnerable (Myers, 1988). Biodiversity often decreases with distance from source populations, and is most constrained by dispersal in areas that are surrounded by dissimilar habitats (Colinvaux, 1993). The decrease in diversity by decrease in distance may in part reflect the relative edge, geographical extent and different historical patterns of barrier formation and consequent biotic disruptions. The biological richness of the landscape was modeled by integrating terrain complexity, ecosystem uniqueness, biodiversity value, species diversity and disturbance.

In India, the department of space (DOS) and department of biotechnology (DBT) are jointly carrying out a study on Biodiversity characterization at landscape level using remote sensing and GIS (Anon., 2002), wherein BR of forest vegetation were generated (Anonymous, 2008). A web-enabled species database on bioprospecting, BIOSPEC having *Query shell* facility was created (Roy and Saran, 2004). Here in this study, we have analysed the BR index and validated the model output using field-derived plant species richness and basal area information in Arunachal Pradesh, Assam and Meghalaya states falling in the Himalayas and Indo-Burma hotspot.

Materials and methods

Study area

The state of Arunachal Pradesh and 15-districts of Assam forms part of the Himalaya hotspot, whereas Meghalaya and southern tip comprising of 5-districts of Assam form part of the Indo-Burma hotspot (Fig. 1). The Himalaya *hotspot* stretches in an arc over 3,000 km of northern Pakistan, Nepal, Bhutan and the north-western and north-eastern states of India. It is home to some of the world's tallest mountain peaks, including *Mt. Everest*. The mountains accommodate a diversity of ecosystems that range, in only a couple of 100 km, from alluvial grasslands (among the tallest in the world) and subtropical broadleaf forests along the foothills to temperate broadleaf forests in the mid hills, mixed conifer and conifer forests in the higher hills, and alpine meadows above the tree line. The Indo-Burma hotspot encompasses 23,73,000 km² of tropical Asia east, of the Ganges-Brahmaputra lowlands. It begins in eastern Bangladesh and then extends across north-eastern India and beyond. Much of Indo-Burma hotspot is characterized by distinct seasonal weather patterns. During the northern winter months dry and cool winds blow from the stable continental Asian high-pressure system, resulting in a dry period under clear skies across much of the south, center, and west of the hotspot (the dry, north-east monsoon). A wide diversity of ecosystems is represented in this *hotspot* including mixed wet evergreen, dry evergreen, deciduous, and montane forests.

The states of Arunachal Pradesh, Assam and Meghalaya fall in *Himalaya-East-Himalaya* biogeographic zone (Rodgers and Panwar, 1988). The region has very high humidity throughout the year, which supports luxuriant growth of epiphytic plants. Human activities do vary according to climate and topographic conditions in these states. Forests on roadsides and slopes experience selective timber extraction are subjected to clear felling and burning for *jhum* cultivation. The state of Arunachal Pradesh encompasses a broad range of ecological habitats varying from grassy meadows to dense humid evergreen forests; disturbed secondary formations to almost virgin natural forests (Anonymous, 2002). In recent decades, shortening of *jhum* cycles, combined with significant population growth has contributed to rapidly increasing levels of forest destruction. The state of Assam is well-demarcated physical unit within the girdle formed by the Eastern Himalaya, Patkai and Naga hills and Garo-Khasi-Jaintia and the Mikir hills. It has three distinct physiographic divisions *viz.* Brahamaputra valley, the Barak Valley and the hills; and thus accommodates varied levels of biodiversity. The state of Meghalaya is a conglomeration of undulating hills mainly with an east-west orientation, separating the valleys of Surma ravines, rivers and rivulets. A prominent number of angiosperms not reported from any part of the country are present in this state. Many rare and endangered species like *Khasi Pitcher* plant - *Nepenthes khasiana* is on the verge of extinction and needs urgent attention before it perishes.

Methodology

Geospatial modeling technique for generation of BR (Tables 1 and 2; Fig. 2a) is widely available (Anonymous, 1999; Anonymous, 2002; Roy and Behera, 2005. Behera *et al*., 2005; Anon. 2008). Satellite remote sensing was used for (i) Delineation of vegetation types and land cover units following 'hybrid classification' technique (Behera *et al*., 2001) and (ii) estimation of vegetation cover. Geographic information system (GIS) was utilized for (i) spatial database development, (ii) analysis of spatial pattern of landscape units (*i.e*., patches), (iii) generation of terrain complexity, (v) biotic disturbance buffer and (v) their integration along with economical, phytosociological and ecological attributes for qualitative labeling of biological richness in various

Table 1 Important attributes of biodiversity considered for the assessment of DI and BR levels of habitats or vegetation types in the Himalaya and Indo-Burma *hotspots*. Only A and B contribute for DI, whereas all six (A-F) attributes contribute for BR assessment (Behera *et al*., 2005)

A. Spatial	(i) Location or extent of vegetation or habitat types (from remote sensing images and ground intelligence) (ii) *Patch-level* *Fragmentation*: Number of non-forest patches *w.r.t.* forest patches *Patchiness*: Density of patches of all types *Porosity*: Density of patches within a particular vegetation type *Interspersion*: Spatial intermixing of vegetation types (*i.e*., count of dissimilar neighbours *w.r.t.* central pixel) *Juxtaposition*: Proximity or adjacency of vegetation types (*i.e*., preference of one habitat to other)
B. Social	Anthropogenic disturbance activities (*i.e*., biotic disturbance buffer of roads and human settlements)
C. Phytosociological	Species diversity (Shannon's index)
D. Physical	Drainage and elevation information to obtain *terrain complexity*
E. Ecological	Number of endemic species to eastern Himalaya, *Ecosystem Uniqueness*
F. Economical	Important economic uses of plant species (*viz*., food, fooder, forage, fibres, fatty oils, drugs, paper, rubber, beverages, spices, essential oils and resins, gums, dyes, insecticides, pesticides and ornamentation); *Total Importance Value* or *Biodiversity Value*

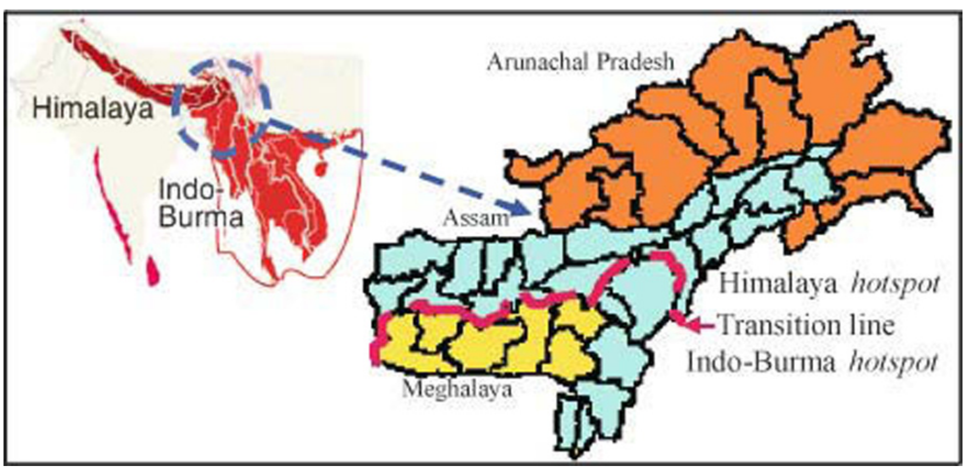

Fig. 1 Location map of the three states in North-East India (i) Arunachal Pradesh, (ii) Assam and (iii) Meghalaya states, at the transition of two *hotspots*; Note that Arunachal Pradesh and 15-districts of Assam form part of Himalaya *hotspot* (above the transition line); and Meghalaya 5-districts of Assam form part of Indo-Burma *hotspot*.

ecological habitats. Global positioning system (GPS) was utilized for (i) locating field sample plots following stratified random sampling with probability proportion to the size (PPS), (ii) gathering positional attributes of plant species and (iii) providing field-points for assessing the classification accuracy of vegetation type map. Phytosociological attributes of vegetation types *viz*. Shannon's diversity was calculated from field data. The spatial attributes i.e., location or extent of habitat or vegetation types and landscape properties were attached to the social attributes (i.e., biotic disturbance buffer) by adopting proportionate weights to derive an intermediate information layer of disturbance index. Different BR levels of vegetation types were computed by integrating disturbance index with physical (i.e., terrain complexity), ecological (i.e., species diversity), phytosociological (i.e., species endemism) and economical (*i.e*., species importance value) attributes using a semi-expert package at 10-levels. Bio_CAP (Anonymous, 1999).

Biological Richness (BR) = f ∫ {ecosystem uniqueness (EU), species diversity (H'), biodiversity value (BV), terrain complexity (TC) and disturbance index (DI)}

$$BR = \{W_{ti}(EU) + W_{ti}(SD) + W_{ti}(BV) + W_{ti}(TC) + W_{ti}(DI)\}$$

where, W_{ti} (t = 0.1 - 1.0) are the proportional weights assigned

A total of 405, 324 and 133 sample plots were laid for Arunachal Pradesh, Assam and Meghalaya states, respectively, accounting for 0.002 to 0.005 % of various vegetation types. Within each sample plot, the measurements on all trees and lianas (20×20 m), shrubs (5×5 m) and herbs (1×1 m) were enumerated (Table 3) (Behera *et al*., 2005). Size of the quadrate and the number of the quadrates laid were determined through species-area-curve (Behera, 2001; Anonymous, 2002; Behera and Kushwaha, 2006). Phytosociological attributes of vegetation types viz., Shannon's diversity was calculated using the field data.

Vegetation type-wise occurrence of species, their genera and families; and their life form distribution is provided in Table 3. For validating the BR model, we categorized the field plots of 405, 324 and 133 for Arunachal Pradesh, Assam and Meghalaya respectively into 10-groups using *data splitting* technique, thereby making the utility of field data differently in development and validation of the model (Olden and Jackson, 2000). Hence, the 862 field plots belonging to 19 vegetation types/groups were splitted and redistributed to 10-levels of BR, wherein the former is independent of the later (Fig. 2b). Further, the sample plots were clubbed for enumeration to study the distribution pattern of tree, shrub, herb and liana species and their endemic subsets; and mean tree BA in various BR levels (Tables 4 and 5). The regression fitness curves were plotted for tree, shrub, herb and liana species and their endemic subsets; and mean tree basal area (BA) at 10-levels of BR to study the state-wise agreement and variations (Fig. 5).

Biodiversity Characterization Package (Bio_CAP)

Bio_CAP, a Geospatial semi-expert package was developed for BR modeling (Table 2) on UNIX platform that uses Arc/Info and ERDAS as back-end software (Anonymous, 1999; Jeganathan and Roy, 1999; Chandrashekhar *et al*., 2003; Behera *et al*., 2005). *Bio_CAP* is an updated version of LAP (Landscape Analysis Package) developed for Biodiversity Characterization at landscape level at the Indian Institute of Remote Sensing (Roy *et al*., 1997; Roy and Tomar, 2000). User-friendly graphics user interface (GUI) is available in *Bio_CAP* that helps to execute the functions through easy pull-down menus and click-and-go types of implementation. The package also provides options for certain basic querying on the processed layers, a viewer with display options, statistics display, management of workspace with file display and delete options. The package requires vegetation type map (grid) contour and/or spot heights, drainage, settlements, transportation network for execution. Bio_CAP recognizes the coding convention of different land and vegetation classes e.g., for computing fragmentation; it considers all the class codes between 1 and 150 as forest classes and between 151 and 255 as non-forest classes. The package was found effective for modeling of BR using

Table 2 Important parameters for landscape pattern analysis (Behera *et al*., 2005)

Fragmentation: (Monmonier, 1974) ***F=(n-1)/(c-1)*** ***n*** = no. of classes present in the n'n window *i.e*., 2 ***c*** = no. of cells considered (*e.g.,* 9if a 3'3 window is used)	- Calculated as the amount of forest patches occurring in a landscape *w.r.t.* non-forest patches. An n'n window convoluted on forest/non-forest map with the criterion of deriving the number of forest patches within the n'n window. A higher value indicates more fragmentation and *vice versa*.
Patchiness (Romme, 1982) $P = \frac{\sum_{i=1}^{N} Di}{N} X100$ ***Di*** = dissimilarity value for the i[th] boundary between adjacent cells ***N*** = number of boundaries between adjacent cells	-Measure of the density of patches of all types or number of clusters in a given mask (*i.e*., measure of number of polygons over a particular area). A high patchiness value indicates more number of patches and a more heterogeneous landscape, which is resulted from disturbance.
Porosity (Forman and Godron, 1986) ***Cpi*** = the numbers of closed patches of i^{th} cover class. $PO = \sum_{i=1}^{n} Cpi$	-Measure of number of patches or density of patches within a particular type, regardless of patch size. Higher porosity value indicates higher interaction among landscape elements and heterogeneous habitats.
Interspersion (Lyon, 1983) $I = \frac{\sum_{i=1}^{n} SFi}{n} \text{ where, } SFi = \frac{Edge}{2\sqrt{\pi * Areaj}}$ Edge = the length of edge, in both x and y-directions Area *j* = area of j^{th} polygon formed by groups in i^{th} cover class	- It is a count of dissimilar neighbours with respect to central pixel or measurement of the spatial intermixing of the vegetation types (shape of each category of cover divided by the boundary of the cover). It is an index that represents the landscape diversity and dispersal ability of species.
Juxtaposition (Lyon, 1983) $J = \frac{\sum_{i=1}^{n} Di(JUXi)}{JUX \max}$ JUXmax = average total weighted edge per habitat unit of good habitat Di = edge desirability weight for each cover type combination, based on field data JUXi = length of edge between combinations of cover types	- It is the measurement of proximity of vegetation. It measures the relative weight assigned to the importance of the adjacency of two vegetation cover types for the species in question - The window is convoluted with the vegetation type map in an iterative manner by assigning adjacency weights derived from field data on the basis of common number of species occurred in two adjacent vegetation types. Higher weight was assigned to the vegetation types that share more number of species and *vice versa*

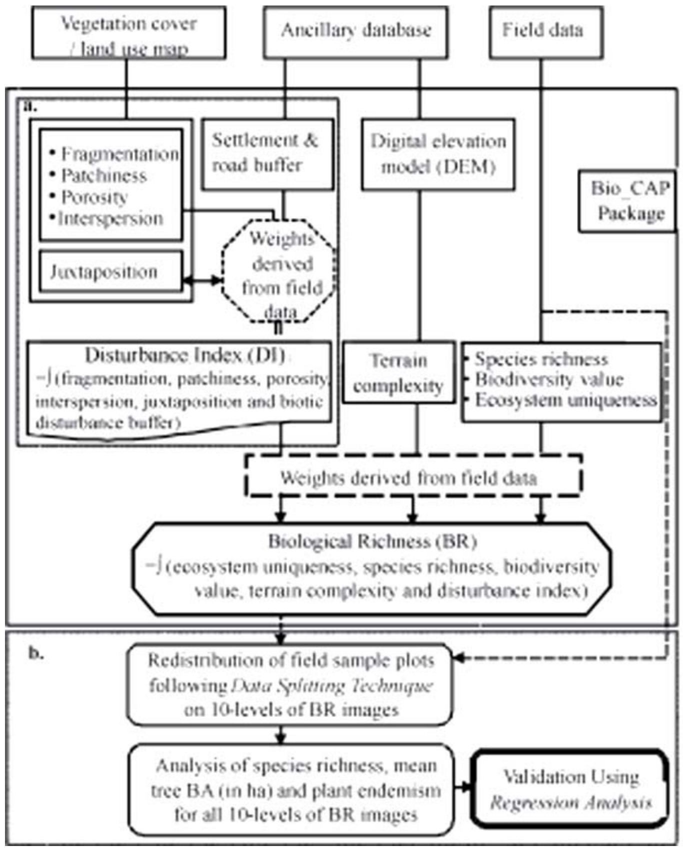

Fig. 2 Paradigm for (a) Assessment of BR of forest sites using geospatial tools (adopted from Behera *et al*., 2005) and (b) Validation of BR models using field plots

geospatial approach (Roy and Behera, 2002; Behera *et al*., 2005; Roy and Behera, 2005).

Results and discussion

Biological richness (BR) assessment

The BR image reflects the spatial extents and distributions of different levels of BR of vegetation units (Fig. 3). Subtropical evergreen forest was found to have highest biological richness followed by tropical semi-evergreen forest in Arunachal Pradesh followed by temperate broad-leaved evergreen and coniferous forests. Degraded forest and other vegetation areas have less biological richness. In Assam southern part of Tinsukia district, parts of Cachar and north Cachar hills showed high BR . It was observed that the lower tropical and subtropical forests harbor more endemic species than the temperate and sub-alpine forests. In Assam, 918.80 km^2 (1.17%) area were having high BR and 18879.08 km^2 (24.04%) were under very low BR; whereas in Meghalaya, 6751.9 km^2 (30.1%) area has high BR and 4984.74 km^2 (22.2%) is under low biological richness (Fig. 4). The non-forest classes, snow and cloud cover were shown separately and no BR-level was attached to them. The BR image provided an index for

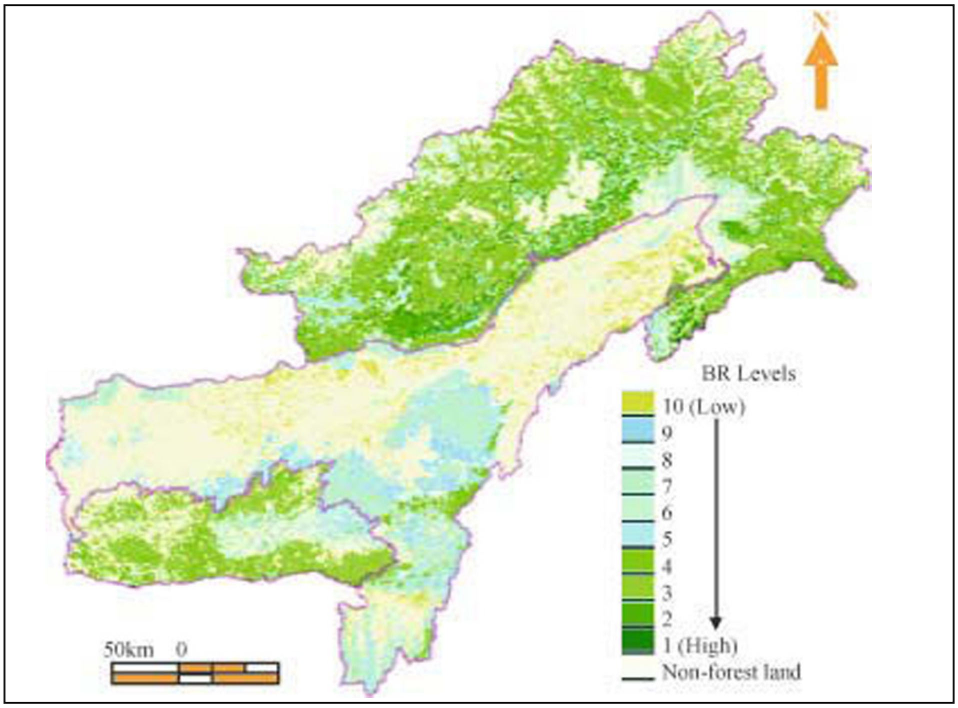

Fig. 3 Biological Richness (BR) image of (i) Arunachal Pradesh, (ii) Assam and (iii) Meghalaya states; Various BR-levels are shown that decreases from 1 to 10

conservation, which can only be judged with a critical understanding of the whole spectrum of biodiversity attributes attached to it.

Field sampling and distribution

All broad vegetation types could be mapped for the states of Arunachal Pradesh, Assam and Meghalaya and field sampling was done (Anonymous, 2002). The distribution of sample plots, genera, families and species (life form-wise) in 17 vegetation types of (a) Arunachal Pradesh, 10-vegetation types of (b) Assam and 4-vegetation types of (c) Meghalaya states were provided in table 3. It is observed that the distribution of sample plots is in accordance with the vegetation area distribution in different states. A maximum of 127 plots are laid in moist deciduous forest of Assam followed by 104 plots in tropical semi-evergreen forest of Arunachal Pradesh. However, they are accommodated in 105 families (with 334 genera) and 145 families (with 398 genera) respectively. Similar trend is also observed for the tropical evergreen forests of Arunachal Pradesh and Assam with 37-plots (101 families and 256 genera) and 60-plots (76 families and 176 genera); and sub-tropical Pine forests of Arunachal Pradesh and Meghalaya with 13-plots (66 families and 100 genera) and 65-plots (48 families and 84 genera) respectively. In general, degraded forest and abandoned *jhum* land showed higher diversity with greater number of shrubs, herbs and lianas; especially invasive and alien species (Table 3). Ecological importance with respect to species endemism was considered to estimate ecosystem uniqueness (Chatterrjee, 1939; Nayar, 1996). 201, 61 and 45 species were found endemic to eastern Himalaya for the states of Arunachal Pradesh, Assam and Meghalaya respectively (Anon. 2002).

Table 3 Distribution of sample plots, genera, families and species (life form-wise) in various vege-tation types of (a) Arunachal Pradesh, (b) Assam and (c) Meghalaya states in (Anonymous, 2002)

Sl	Vegetation types	No. of Plots	No. of Genera	No. of families	No. of species			
a.	**Arunachal Pradesh**				Trees	Shrubs	Herbs	Lianas
1	Tropical semi-evergreen forest	104	398	145	354	239	350	58
2	Tropical evergreen forest	37	256	101	176	127	211	42
3	Moist deciduous forest	27	183	84	92	43	133	17
4	Sub-tropical evergreen-I	54	385	147	330	171	333	56
5	Sub-tropical evergreen-II	13	222	103	71	65	211	25
6	Temperate broadleaved forest	57	319	140	183	117	273	32
7	Temperate conifer forest	21	116	65	31	27	106	6
8	Sub-tropical Pine forest	13	100	66	16	33	61	7
9	Fir forest	13	44	28	9	16	24	4
10	Rhododendron forest	12	57	36	6	16	49	1
11	Grasslands	13	38	21	1	14	30	0
12	Hollock	3	54	40	7	11	27	7
13	Hollong	2	28	23	4	1	15	3
14	Bamboo	6	48	39	6	14	24	4
15	Abandoned *jhum* forest	14	183	94	76	53	151	57
16	Degraded forest	10	129	75	37	31	88	13
17	Riverain	5	82	58	18	9	55	7
b.	**Assam**							
1	Tropical semi evergreen forest	25	158	72	140	42	46	22
2	Tropical evergreen forest	60	176	76	190	42	39	29
3	Moist Deciduous forest	127	334	105	284	124	149	83
4	Sal forest	10	62	40	26	15	20	4
5	Bamboo	20	68	40	55	14	16	15
6	Teak forest	13	52	32	20	17	20	8
7	Pine	9	26	19	23	9	5	8
8	Abandoned *jhum* forest	6	60	28	22	15	23	6
9	Degraded forest	38	215	88	122	50	88	20
10	Grasslands	16	76	47	20	16	47	7
c.	**Meghalaya**							
1	Tropical semi evergreen forest	31	180	84	170	54	65	27
2	Sub-tropical evergreen forest	31	213	107	183	85	99	28
3	Sub-tropical pine forest	65	84	48	51	26	39	3
4	Sal forest	2	33	22	22	5	11	9

Validation of BR

In general, the number of tree, shrub and liana species and mean BA demonstrated a decreasing trend with lowering of BR for all three states falling under both the biological *hotspots* (Fig. 5). Among the three states, the state of Arunachal Pradesh has shown very high correlation with R^2 value of >0.7 except for

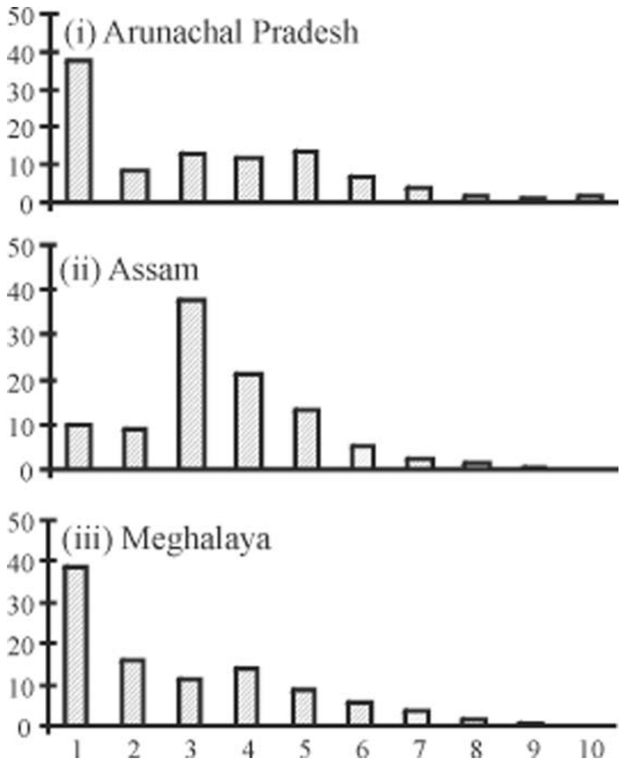

Fig. 4 Percentage area (Y-axis) distribution of BR in (i) Arunachal Pradesh, (ii) Assam and (iii) Meghalaya states; X-axis represents various levels of BR.

herbs i.e., 0.9 for trees, 0.82 for shrubs, 0.82 for lianas and 0.7 for mean tree basal area. Meghalaya demonstrated a high R^2 value for trees (0.9), and medium value for shrubs and herbs (0.55), for mean tree BA (0.45); and low correlation for lianas (R^2 = 0.15). The state of Assam showed high correlation for tree (R^2 = 0.76), medium value for herbs (R^2 = 0.47) and very low correlation for lianas (R^2 = 0.14), shrubs (R^2 = 0.06) and mean BA (R^2 = 0.04). However, the number of endemic species increased with decrease in biological richness levels for Meghalaya (R^2 = 0.74) and Arunachal Pradesh (R^2 = 0.11); and decreased (R^2 = -0.1) for the state of Assam. Though, endemism is explained by biogeographical processes, here it can be specifically be understood by the complex physiognomy that the state of Meghalaya and Arunachal Pradesh offers leading to microclimates; thereby higher species endemism. Therefore, the slope values in regression across different parameters mostly represent the model performance for the landscape.

Biological richness is related to higher species diversity, higher degree of ecosystem uniqueness, higher degree of terrain complexity and lower levels of disturbance. Deforestation levels are high in the lowland regions of Arunachal Pradesh due to high levels of anthropogenic pressures (Khan *et al*., 1997). Increasing population growth and the resultant increase in shifting cultivation and industrialization are major proximate factors contributing to deforestation in the state of Arunachal Pradesh (Shukla and Rao, 1993). Arunachal Pradesh is affected mainly near roads and settlements (Roy and Behera, 2005). Assam being in the valley region is dominated by permanent cultivation and tea gardens, where the loss of biodiversity has been attributed to habitat loss and fragmentation (Singh *et al*., 2001). The prime reason for decline of biodiversity in Meghalaya is shifting cultivation (Porwal *et al*., 2000; Roy and Tomar, 2001). In Arunachal Pradesh, vegetation heterogeneity is primarily dominated by prevailing climatic conditions, slope, aspect, terrain conditions and vegetation disturbance regimes; whereas in Assam and Meghalaya, it is modified due to human interactions.

Despite lower number of sample plots, tropical semi-evergreen forest of Arunachal Pradesh showed higher taxonomical diversity in comparison to moist deciduous forest of Assam with 145 families (with 398 genera) and 105 families (with 334 genera) respectively. Tropical evergreen and subtropical Pine forest also showed higher taxonomic diversity for Arunachal Pradesh of the Himalayas *hotspot* and Meghalaya and southern Assam states of the Indo-Burma *hotspot* respectively. Higher species and taxonomic richness in degraded forests and abandoned *jhum* lands indicates the triggering effect of moderate level of disturbance for higher species diversity, particularly herbs and lianas, especially invasive or alien species (Table 3).

Each sample plots may have different spatial and biological characteristics leading to local variations at different levels of BR. However, in general the regression analysis demonstrated good agreement between various levels of BR; and field-derived species richness and mean tree BA (Fig. 5). BR was observed to have good agreement with tree, shrub and liana species and mean tree BA for Arunachal Pradesh followed by Meghalaya and Assam, whereas herbs were found to be in good agreement with BR in Meghalaya followed by Assam and Arunachal Pradesh. The regression curves might represent the conditions reflecting change in compositional structure of the vegetation communities with the varied levels of BR. Though, endemism is chiefly explained by biogeographical processes, the increase in species endemism with decreasing BR-levels for Meghalaya and Arunachal Pradesh indicates that the lowest BR-levels should be given priority for conservation. High degree of agreement of BR with field data for the states of Arunachal Pradesh and Meghalaya indicate that the terrain complexity would have contributed significantly, thereby leading to creation of lot of microclimates in the states. Assam with relatively simpler terrain would have received less contribution from the physical attribute and thereby behaved as a different landscape in transforming the ecological patterns and processes onto BR index.

The overall rate of endemism has followed a declining trend from tropics to subtropics, temperate and alpine zone which is also evident from the discussion of Heywood and Watson (1995). Myers‘s (1988) observation was that tropics harbor more endemic species in comparison to the other zones. Behera and Kushwaha (2007) have found that species richness decreased and its endemic subset increased from across altitudinal gradients of Arunachal Pradesh. Another study by Behera *et al*., (2002) indicates that the rate of endemism is more in tropics in comparison to other regions which could probably be attributed to various climatic factors prevailing in this area. Endemism seems to decrease along BR-levels in Arunachal Pradesh and Meghalaya, but varies directly in Assam. This observation indicates that the endemic plants are not concentrated in higher BR regions, rather distributed in edges and areas susceptible to interactions. However, the trends in endemism pattern adequately describe the BR properties of the landscapes in the state of Meghalaya and Arunachal Pradesh attributed to their complex physiognomy.

Conclusions

Utilization of geospatial tools with limited field survey and landscape pattern analysis proved successful in combining field and satellite surveys to compute the BR status of forest vegetation. It was also the intention that the technique adopted here for the study would be suitable for rapid and wider

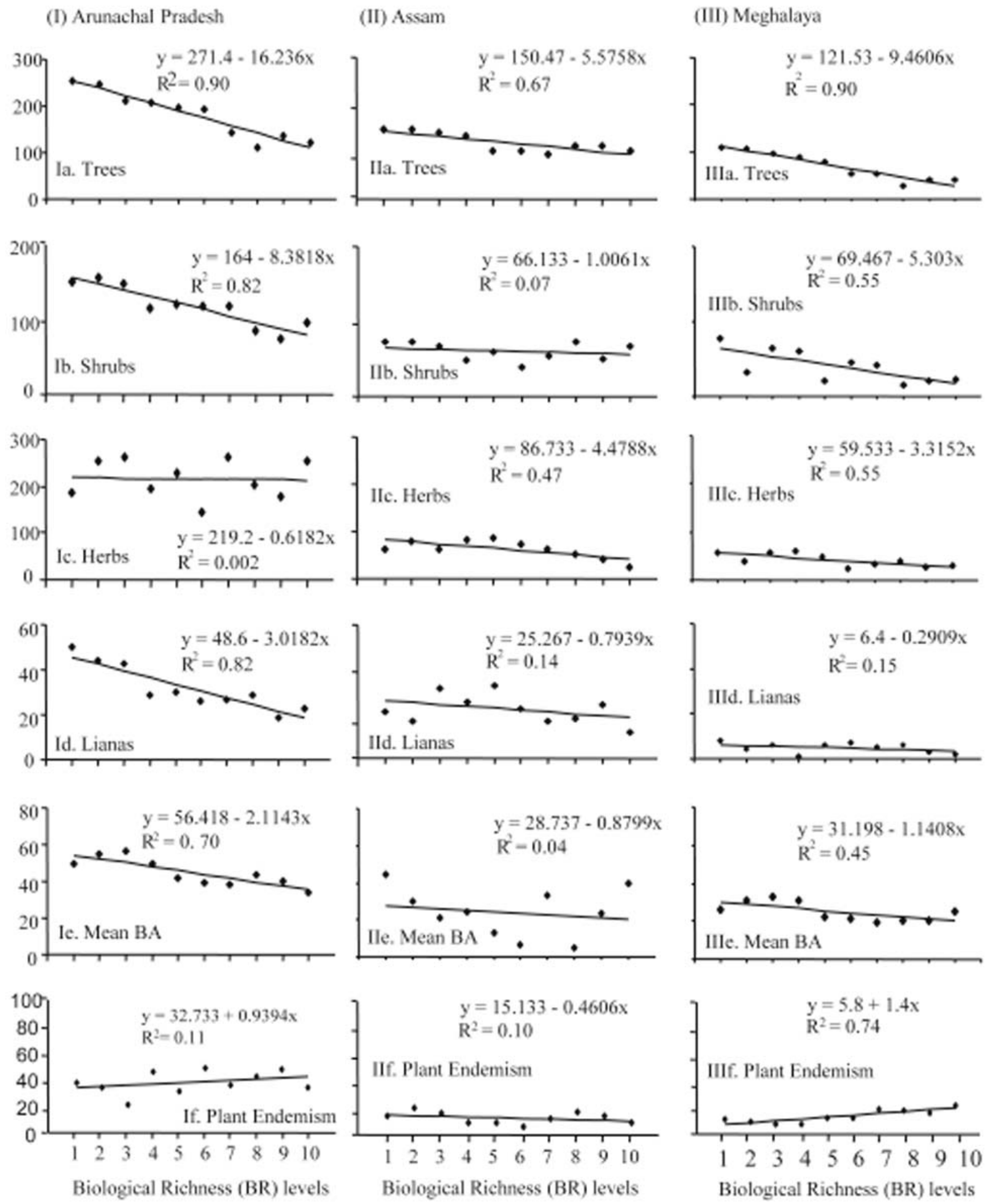

Fig. 5 Distribution of number of (a) tree, (b) shrub, (c) herb, (d) liana species (e) Mean BA and (f) plant endemism across various BR levels for (I) Arunachal Pradesh, (II) Assam & (III) Meghalaya states; Y-axis represents number of species. BR-level decreases from 1 to 10 along X-axis

application in assessing BR of broad ecosystem habitats and to transfer the technology to other countries where quick assessment is the need; such ideas demanded relatively low cost, adequate software support, limited field survey, general robustness of techniques and equipments and a team of mult-disciplinary ecologists (Behera and Roy, 2009). The validation results showed that BR pattern of Arunachal Pradesh and Meghalaya are different from that of Assam, which is dominated by simpler terrain and agricultural lands. High number of species endemism was also noticed in Arunachal Pradesh and Meghalaya than Assam. H', EU and BV were directly derived from the field data by calculating the total number of species present, total number of endemic species (to eastern Himalaya) present and economic importance of the species present in each forest type respectively. Therefore, splitting the field data into 10-BR levels almost forms new datasets for BR-validation. Utilization of data from independent sampling might lead to some other results, but quite expected to result similar pattern (Kumari *et al*., 2010).

The study validates the BR index, thereby provides confidence for its acceptability. BR index, described elsewhere as a function of six biodiversity attributes *i.e*. spatial, phytosociological, social, physical, economical and ecological. The slope values in regression (Fig. 5) across different parameters mostly represent the model performance for the landscape. Multi-season field sampling for shrubs, herbs and lianas might demonstrate better model validation like trees. Though, endemism is chiefly explained by biogeographical processes, the increase in species endemism with decreasing BR-levels for Meghalaya and Arunachal Pradesh indicates that; more so it is explained with physiognomy and varied microclimates prevailed here. The model seems to be better suitable for forested and non-plain terrains than their counter parts, that can be ascertained by 'sensitivity analysis' of various attributes integrated into it. Though, this validation exercise offers wider acceptability of the BR model.

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References

Anonymous (1998) Biodiversity characterization at landscape level using geographic information system and geographic information system. Project Manual, Indian Institute of Remote Sensing (NRSC), DOS, Dehradun

Anonymous (1999) Bio_CAP User manual for landscape analysis and modeling biological richness, Indian Institute of Remote Sensing (NRSC), DOS, Dehradun

Anonymous (2008) Biodiversity characterization at landscape level using geographic information system and geographic information system. Project Manual, Indian Institute of Remote Sensing (NRSC), DOS, Dehradun

Anonymous (2002) Biodiversity Characterization at Landscape Level in North East India using Satellite Remote Sensing and Geographic Information system, Indian Institute of Remote Sensing (NRSC), DOS, Dehradun

Baker WL and Cai Y (1992) The role programs for multiscale analysis of landscape structure using the GRASS geographic information system. *Landscape Ecology* 7:291-302

Behera MD and Kushwaha SPS (2007) An analysis of altitudinal behavior of tree species in Subansiri district, Eastern Himalaya. *Biodiversity and Conservation* 16:1851-1865

Behera MD and Roy PS (2009) Scope of India's Biodiversity Database in Global Monitoring of Vegetation Variables, *4th Global Vegetation Workshop*, June 16-19, 2009. The University of Montana, Missoula, USA.

Behera MD (2001) *Biodiversity Characterization at Landscape Level in Subansiri District, Arunachal Pradesh (Eastern Himalaya) Using Remote Sensing and GIS*. Ph.D. Thesis, Gurkul Kangri University, Hardwar India

Behera MD, Jeganathan C, Srivastava S, Kushwaha SPS and Roy PS (2000) Utility of GPS in classification accuracy assessment. *Current Science* 79(12): 1996-1700

Behera MD, Kushwaha SPS and Roy PS (2002) High plant endemism in Indian Hotspot- Eastern Himalaya. *Biodiversity and Conservation* 11(4): 669-682

Behera MD, Kushwaha SPS and Roy PS (2005) Rapid assessment of Biological Richness in a part of Eastern Himalaya - an integrated three-tier approach. *Forest Ecology and Management* 207: 363-384

Behera MD, Kushwaha SPS and Roy PS (2001) Forest vegetation characterization and Mapping using IRS-1C Satellite Images in Eastern Himalayan Region. *Geocarto International* 16(3):53-62

Burton PJ, Balisky AC, Coward LP, Cumming SG and Kneeshaw DD (1992) The value of managing for biodiversity. *The Forestry Chronicle* 68(2):225-237

Champion HG and Seth SK (1968) *Revised Forest Types of India*. Government of India Publications, New Delhi

Chandrashekhar MB, Singh S and Roy PS (2003) Geospatial modeling techniques for rapid assessment of phytodiversity at landscape level in western Himalayas, Himachal Pradesh. *Current Science* 84:663-670

Chatterjee D (1939) Studies on the Endemic Flora of India and Burma. *J Asiat Soc Bengal* 11 5(3):19-67

Chuvieco E (1999) Measuring changes in landscape pattern from satellite images: short-term effects of fire on spatial diversity. *Int J Remote Sensing* 20(12):2331-2346

Colinvaux P (1993) *Ecology*, 2nd edition. John Wiley Publisher. New York

Coulson RN, Lovelady CN, Flamm RO, Spradling SL and Saunders MC (1990) Intelligent geographic information systems for natural resource management. In: M.G. Turner and R.H. Gadner, (eds.). *Quantitative Methods in Landscape Ecology* 153-172. Ecological Studies-82 NewYork: Springler-Verlag

Dillworth ME, Whistler JL and Merchant JW (1994) Measuring landscape structure using geographic and geometric windows. *Photogrammetric Engineering and Remote Sensing* 60: 1215-1224

Farina A (1998) *Principles and Methods in Landscape Ecology* (ed.) Chapman and Hall, London

Felding AH and Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24:38-49

Jeganathan C and Roy PS (1999) Geospatial semi-expert system for landscape analysis. *Proceedings International Conference on Geoinformatics for Natural Resource Assessment, Monitoring and Management, Geoinformatics and Beyond*. 9-11 March, IIRS, Dehradun

Khan ML, Menon S and Bawa KS (1997) Effectiveness of protective area network in biodiversity conservation: a vase study of Meghalaya state. *Biodiversity and Conservation* 6:853-868

Kumari S, Behera MD and Tewari HR (2010) Identification of Potential Ecotourism Sites in West District using geospatial tools, Sikkim. *Tropical Ecology* 51(1):75-85

Lidicker WZ Jr. (1995) The landscape concept: something old, something new. In: Lidicker, W.Z. Jr (ed.) *Landscape approaches in mammalian ecology and conservation*. University of Minnesota Press, Minneapolis, 3-19

Mayer DG and Butler DG (1993) Statistical validation. *Ecological Modelling* 68:21-32

Myers N (1988) Threatened biotas: 'hotspots' in tropical forestry. *The Environmentalist* 8:1-20

Nayar MP (1996) *Hot Spots of Endemic Plants of India, Nepal and Bhutan*. Tropical Botanic Garden and Research Institute, Trivandrum

Noss RF, LaRoe ET and Scott JM (1995) *Endangered ecosystems of the United States: a preliminary* *assessment of loss and degradation*. Biological Report 28 U.S. Department of Interior National Biological Survey, Washington, D.C. 59

Olden JD and Jackson DA (2000) Torturing data for the sake of generality: How valid are our regression models? *Ecoscience* 7(4):501-510

Orians GH (1993) Endangered at what level? *Ecological Applications* 31:206-208

Porwal MC, Talukdar G, Singh H, Tripathi OP, Tripathi RS and Roy PS (2000) Biodiversity Characterization at landscape level using remote sensing and GIS. *Proceedings of Biodiversity and Environment-Remote Sensing and Geographic Information System Perspectives*, Indian Institute of Remote Sensing (NRSC), DOS, Dehradun, pp 206-215

Ricketts TH, Dinerstein E, Olson DM, Loucks CJ, Eichbaum W, DellaSala D, Kavanagh K, Hedao P, Hurley PT, Carney KM, Abell R, and Walters S (1999) *Terrestrial ecoregions of North America: a conservation assessment*. Island Press, Washington, DC pp. 485

Rodgers WA and Panwar SH (1988) Biogeographical classification of India. New Forest, Dehradun.

Roy PS and Behera MD (2002) Biodiversity assessment at landscape level. *Tropical Ecology* 43(1):151-171

Roy PS and Behera MD (2005) Biological richness assessment along the eastern Himalayan altitudinal zones in Arunachal Pradesh, India, *Current Science* 88(2):250-257

Roy PS and Saran S (2004) Biodiversity Information System for North East India. *Geocarto International* 19(3):3-8

Roy PS and Tomar S (2001) Landscape cover dynamics pattern in Meghalaya. *International Journal of Remote of Remote Sensing* 22(18):3813-3825

Roy PS, Tomar S and Jeganathan C (1997) Biodiversity characterisation at landscape level using satellite remote sensing. *NNRMS Bulletin* 12-18

Shukla GP and Rao K (1993) Status of minor forest produce in Arunachal Pradesh. *Arunachal Forest News* 11(2):8-18

Whittaker RH (1977) Evolution of species diversity in land communities. *Evolutionary Biology* 10:1-67