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Spatial patterns of biodiversity of lichens

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Abstract

With its diverse ecological conditions, and its geographical location at the confluence of three of the eight biogeographic realms, Indian landmass supports rich diversity of flora accounting for above 10% of the 20,000 species of lichens so far described in the world. The paper reviews the status of the lichenological research in the country and presents species diversity patterns at different spatial scales ranging from global, national through regional to the local landscapes. Ecological patterns emerged from the recent studies within India are also assessed. Knowledge gaps are identified and conservation implications are discussed.

Keywords: Biodiversity, conservation, ecological patterns, lichens, landscape, spatial distribution patterns.

1. Introduction

1.1. *Rationale*

India, as a party to the Convention on Biological Diversity (CBD), has obliged to document a whole range of organismic diversity within its territorial boundaries, make all attempts to conserve these bioresources and monitor the efficacy of the conservation measures adopted.[1–3] With the unprecedented biotechnological revolution and emerging patent regimes over modified life forms and their products, diversity of all, even seemingly insignificant life forms such as the lichens, has acquired the potential for commercial application.[4–7] At the same time, this diversity is being eroded rapidly with fears that at least 10% of all the species will become extinct over the next few decades.[8, 9] It is in this context that we need to first urgently assess the country's sovereign heritage of biological diversity so far documented at different time and spatial scales, be they ants in the dryland ecosystems of Gujarat, wood-rotting fungi in the tropical forests of the Western Ghats or lichens or liverworts from the Himalayas. This exercise may help judicious resource allocation for furthering research and pave the way for effective monitoring, conservation and sustainable utilization of the resources. In this paper, an effort is made to present a detailed analysis of the patterns of biodiversity of lichens in India based on published and unpublished literature available with the author scaling from global, national through regional to the local landscapes. An attempt is made to critically assess the information and identify knowledge gaps and then suggest appropriate conservation measures besides highlighting ecological and economic importance of these least appreciated organisms.

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1.2. *Lichens: an overview*

Lichens are fascinating composite organisms evolved and diversified after a symbiotic association between algae and fungi.[10, 11] They dominate other groups of organisms in as much as 8% of the earth's surface.[12, 13] The associated entity grows at an average rate of 1–5 mm per year and persists for tens or hundreds of years on their substratum. The growth forms of lichens are usually conspicuous on the substrates, forming gray, green, dark brown and orange patches. They are categorized primarily based on their morphology and size into three major types, viz. crustose (crust like), foliose (leaf like) and fruticose (shrubby). The lichens belonging to the former category are called microlichens and the latter two are referred to as macrolichens.[14, 15] They colonize a great variety of substrates such as rocks, soil, humus, wood substrates as tree trunks, branches and logs, animal shells, bones, insect backs, synthetic materials as plastic taps and substrates derived from mineral sources such as bricks, cement, concrete roofs and walls, and glass and iron, amongst others.[10, 16–18] They are significantly reliable indicators of environmental pollution,[19, 20–26] climatic change[27–30] and ecological continuity.[31–38]

A number of lichen species are reportedly used in traditional or folk medicines,[39–48] sold as condiments in the Indian bazaars,[5, 41] cooked as a vegetable curry by the tribal people of Sikkim Himalaya particularly during scarcity of food and are even utilized as common livestock fodder in some places of South India.[45, 49] They are also well known to serve as a staple diet for the Alaskan Reindeer[50, 51] and the Himalayan Musk deer.[52] Notably, a few species such as *Peltigera canina, Parmelia tinctorum* and *Umbilicaria pustulata* have been demonstrated to contain significantly high levels of edible proteins and carbohydrates along with some essential amino acids that may prove useful in preparing drugs to cure certain liver diseases apart from their potential food value.[53, 54] Some of the lichen contents have reportedly shown antitumor activity[55] and even inhibitory effects on HIV in *in vitro* conditions,[56] besides many others possessing antimicrobial properties[57, 58] that may be tapped for further research and development. Many of the lichen species have proved economically very beneficial and continue to hold significant commercial implications particularly in cosmetic and perfumery industries.[59–62] Approximately 10% of the lichen species contain cyanobacteria as primary symbiont that contribute to nitrogen economy of the ecosystems to the tune of 40 kg ha^{-1} yr^{-1} as reported in the birch-pine forests of Sweden.[37, 63, 64] These lichens with rich source of nitrogen may therefore be harvested as green organic manure by the highly biomass and agriculture-based human societies like India.[65–67] Ironically, these very natural sources are being wasted unnoticed with unsystematic forest management practices and due to various other factors responsible for loss of lichen biodiversity.[52, 68, 69] Systematic assessment and conservation of lichen communities are therefore urgently required so as to maintain the economic and ecological balance to preserve environment, food and health security of India and for aesthetic reasons.

2. Global to national patterns of diversity

On the basis of recent monographic revisions of a number of widespread genera and the collection of lichens from different areas of the world, previously unknown or poorly explored, it has been projected that a realistic world total for lichen species is closer to 20,000. However, the present consensus of known lichen species worldwide varies from 13,500 to 17,000.[70] It may therefore be reasonable to say that at present we know 67–85% of the world's lichen species. This estimation is quite contrary to documented 6-18% or possibly be near 20% of quantitatively estimated total species of the world, as only 1.7 million are so far known to science as compared to the global estimates of 10–30 million species.[9, 71, 72] Temperate areas with wide variations of habitats, climate and geology are known to be 'hot spots' of lichen diversity as opposed to the general trend of higher plant diversity being concentrated to the tropics. However, much less is known about tropical lichens whose biodiversity tends to be the richest in canopy vegetation, which has still been very poorly sampled.[73] We know equally very little of the canopy lichen communities from even relatively more exhaustively surveyed open temperate forests of India as compared to the dense tropical forests that call for sophisticated sampling techniques with skilled manpower.[74] One of the recent global assessments on the status of lichens and their conservation also revealed that majority of the lichen surveys were concentrated in temperate and boreal zones of the world as opposed to the tropics, where there are extensive areas of forests forming a major component of earth's vegetation.[36, 75] If we consider currently known lichen diversity as a 20% of total expected number of species, it adds 80,000 to the 20,000 species so far described in the world. However, there is no quantitative information on the proportion of efforts put in different areas surveyed all over the world, but the fact is that much of the lichen-rich areas remain unexplored. An expected world total for lichen species would therefore be close to 100,000.

India is one of the 12 megadiversity countries in the world with a potential of supporting as high as 500,000 species of sexually reproducing organisms, of which only 27% have so far been described.[2, 70, 76] The number of species described from India includes 17,500 flowering plants, 2021 lichens, 2825 bryophytes and 86,874 species of animals that include 59,352 species of insects, accounting for 7% of the total described animals and flowering plants of the world.[76, 77] However, in contrast to the global estimations of 10–30 million species, India would harbor between 2% and 5% of this variation commensurating with its share of 2.2% land surface of the earth.[2, 9] This tremendous diversity of species carrying large genetic variations within them is believed to be due to India's great variety of ecological conditions and its position at the confluence of Palaearctic, Afrotropical and Indomalayan biogeographic realms of the world.[78, 79] If Indian landmass supports 7% of the total estimated 100,000 species of lichens tuning with the most studied taxa of flowering plants and higher animals, it still adds 5,000 to the so far described 2,000 species in the country. However, in terms of species–area ratio, India would harbor only 2200 species of lichens commensurating with its 2.2% land area of the world. Thus, the total number of estimated species of lichens in India would vary between 2200 and 7000 species. Singh and Sinha's projection of 3500 species of lichens from Indian subcontinent therefore seems to be realistic.[80] Although inventorying of the lichens is highly incomplete, India still emerges as the fifth richest country sharing 10.11% of 20,000 species of lichens recorded in the world.[70] However, it ranks third higher in terms of the land area as compared to smaller countries like France, Sweden and Norway, which rank even higher than India in lichen diversity (Table I). This seems to reflect on the relative extent of the efforts put in for lichen surveys in these countries. Most European countries including United Kingdom are very well known for lichenological studies.

Table I
Ten countries of high lichen diversity ranked based on their area, genus and species richness with respect to a total of 20,000 species of lichens recorded so far in the world

Country	Area in x 10,000 sq. km	Number of Genera	Number of Species	Rank based on Area	Rank based on Genera	Rank based on Species	% of world species
USA & Canada	1828.78	401	3409	1	1	1	17.05
Australia	768.23	299	2499	2	2	2	12.50
India*	328.73	248	2021	3	5	5	10.11
Argentina	277.79	122	942	4	10	10	4.71
Mexico	196.72	130	997	5	9	8	4.99
Sweden & Norway	73.55	216	2142	6	6	4	10.71
France	54.41	181	2200	7	7	3	11.00
Philippines	30	137	974	8	8	9	4.87
New Zealand	26.81	243	1162	9	4	7	5.81
United Kingdom	23.06	250	1600	10	3	6	8.00

Sources: Groombridge(1992)[70]; *Singh and Sinha (1997)[80]

3. Regional patterns of diversity and endemism

Singh and Sinha,[80] and Upreti[81] have independently attempted assessing national biodiversity of lichens after Awasthi's[14, 15] extensive keys to the macro- and microlichens that cover contributions of almost all including the classic works of Nylander[82], Smith[83] and Poelt.[84] While Upreti[81] proposed six lichen regions with no depicted boundaries on the map, Singh and Sinha[80] divide the whole Indian surface into 8 lichen regions with distribution of 2021 species. However, the authors of both the publications agree on classifying lichen flora into Tropical, Temperate and Alpine vegetations broadly based on climate and altitude. Regional diversity patterns with the levels of endemism are reproduced as Table II a and b. These assessments are however not comparable as both seem to have different origins in terms of the compilation of the data. Nevertheless, the data presented by Singh and Sinha[80] seem to be more robust with up-to-date coverage of literature along with depicting qualitative phytogeographic boundaries on a map as compared to Upreti[81] where the only source of lichen diversity sited was that of Awasthi,[85] clearly weakening the assessment. To avoid confusion and poor quality of information, further discussion on the regional assessment will therefore be restricted to Singh and Sinha.[80] Relative levels of species diversity in relation to the area and per cent endemism for each of the 8 lichenogeographic regions are further depicted in a map generated using GIS package of Mapinfo version 4.1 (Fig. 1). These 8 lichen regions have been ranked in ascending order based on their area, species and endemism (Table IIb).

While Western Ghats, Western and Eastern Himalayas, harboring above 550–800 species, seem to be rich centres of lichen diversity, Andaman and Nicobar emerges as lichen 'hot spot' ranking first in terms of endemic species with smallest area as compared to the rest of the lichenogeographic regions in the country. There seem to be a higher concentration of endemics in the tropics than in the temperate to alpine regions of the Western Himalayas. Lower endemism in the Himalayas is probably due to greater affinity of their elements with Europe and arid regions of Central and Western Asia. Very poorly surveyed Eastern Ghats and Central Indian

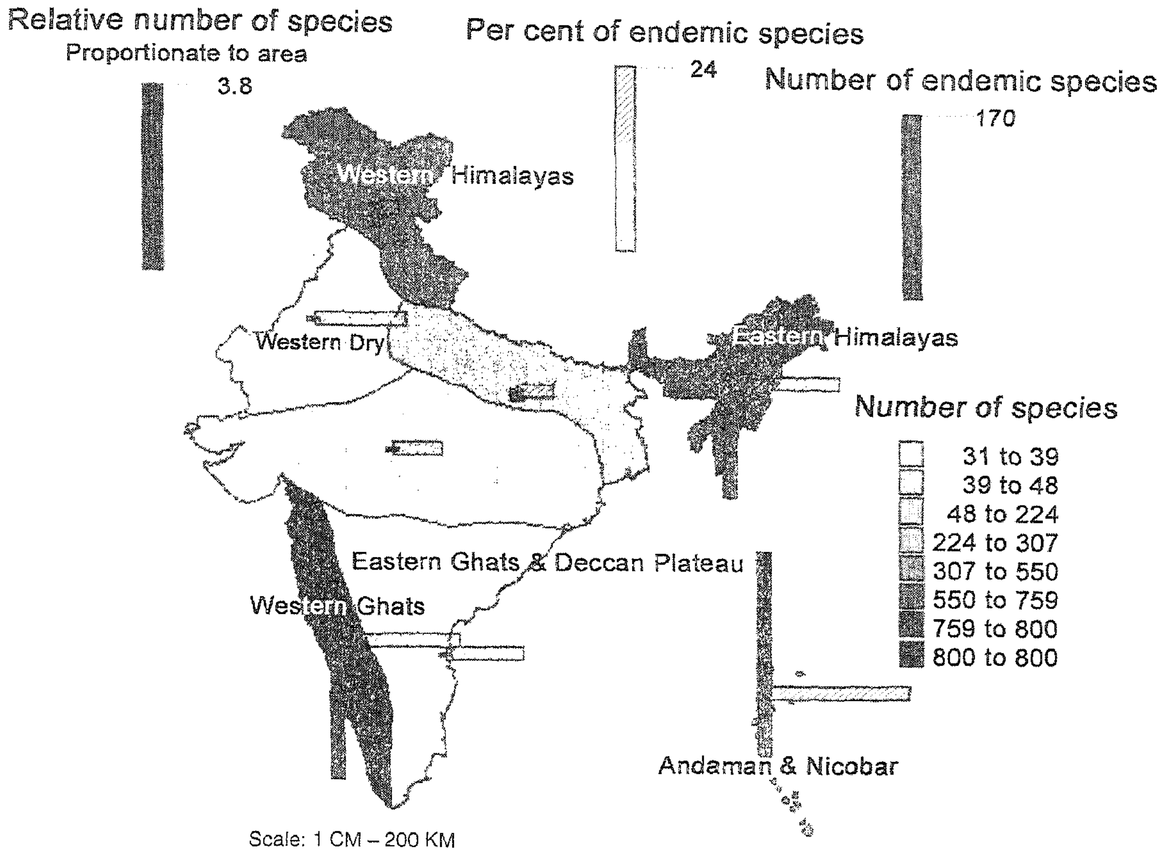

FIG. 1. Eight lichenogeographic regions of India depicting levels of species diversity and endemism in relation to their areas.

regions with dense forests may equally prove biological treasure troves of lichens as in the case of Western Ghats, provided, investigations are properly organized to explore these virgin areas. The predominance of agriculture in the Gangetic plains and the very dry and arid climatic conditions in the western parts of the country are not conducive for the growth of lichens. However, the taxa adapted to these dry climatic conditions render endemism as high as 15% of the total regional species pool.

Although this regional information sounds informative, the classification suffers from a series of shortcomings as these neither match with Udvardy's[86] and Rodger and Panwar's[87] biogeographic regions nor comply with the most recently acclaimed 16 biogeographic provinces with 42 vegetation types in India by Gadgil and Meher-Homji.[79] This in turn made comparative studies and assessments in relation to other taxonomic groups extremely difficult. Independent biogeographic classification without explaining its basis with merits and the possible demerits of the earlier biogeographical divisions may only liquidate interdisciplinary biodiversity research and further leave lichenology in isolation. We need to generate and link the available information to other taxonomic groups as well for any meaningful biodiversity assessments. However, Upreti[81] further attempts to subdivide the tropical lichen vegetation based on the broad tropical forest types, but does not give any background information on such unsatisfactory attempts as by Champion and Seth[88] on which Puri *et al.*[89] bring out a number of

Table IIa
Levels of lichen diversity and endemism in six lichenogeographical regions of India (after Upreti [81])

Lichen regions	Number of		% of 1850	% of	Ranks based on	
	Species	Endemic sp.	species	Endemism	Species	% Endemism
Central Himalayas	323	24	17.46	7.43	4	1
Andaman Islands	211	13	11.41	6.16	6	2
South India	627	23	33.89	3.67	1	3
Eastern Himalayas	333	11	18.00	3.30	3	4
N.W. & W. Himalayas	344	11	18.59	3.20	2	5
Central India	219	7	11.84	3.20	5	5

deficiencies including a confusion between biotic and climatic influences. Lichens are an integral part of dominant vegetation that forms the basis of ecological diversity subjected to different environmental regimes and evolutionary histories.[74] Future lichen explorations may therefore be undertaken with reference to the 16 biogeographic provinces and 42 vegetation types representing the basic units of ecological and biological diversity of the Indian subcontinent so that the assessment would be more objective, transparent, comparable and possibly complete.

4. Patterns of diversity within state political boundaries

Although the biological entities do not strictly consider the political boundaries of the states, the assessment of given information enclosed inside these limits may help strengthen policy measures related to conservation and management of bioresources within and between the states. Moreover these assessments give insight into the levels and quality of information and may help updating existing knowledge and pave the way for further research and development. Six states and a union territory, viz. Andaman & Nicobar, are chosen in the present review for which published or unpublished but reliable information is available[81, 90, 91] (Sinha, BSI, Sikkim, pers. commun., 1999). Areas and forest cover of these regions along with their numerical

Table IIb
Levels of lichen diversity and endemism in 8 lichenogeographical regions of India (after Singh and Sinha[80])

Lichen regions	Approx. area (sq. km)	Number of		% of 2021 Species	% of Area	% of sp-area ratio	% of Endemism	Ranks based on		
		Species	Endemic sp.					Area	Species	% of Endemism
Central India	918500	48	4	2.38	28.11	0.01	8.33	1	6	6
Eastern Ghats and Deccan Plateau	647000	31	4	1.53	19.80	0.00	12.90	2	8	5
Western dry region	411000	39	6	1.93	12.58	0.01	15.38	3	7	4
Gangetic plains	383100	224	14	11.08	11.73	0.06	6.25	4	5	7
Western Himalayas	342600	550	22	27.21	10.49	0.16	4.00	5	3	8
Western Ghats	288600	800	161	39.58	8.83	0.28	20.13	6	1	2
Eastern Himalayas	268300	759	133	37.56	8.21	0.28	17.52	7	2	3
Andaman and Nicobar Inslands	8249	307	73	15.19	0.25	3.72	23.78	8	4	1

Areas approximated using Mapinfo version 4.1

Table III
Levels of lichen diversity and forest cover in seven well-explored states of India

States	Lichen zone	Area (sq. km)	Forest cover (sq. km#)	Number of species	% of Total species	Ranks based on		
						Area	Forest	Species
Nagaland	E. Himalayas	16579	14356	348	18.81	5	5	1
Manipur	E. Himalayas	22327	17885	260	14.05	4	3	2
Andaman & Nicobar$	Andamans	8249	6651	211	11.41	6	6	4
Sikkim*	Central Himalayas	7096	3124	215	11.62	7	7	3
Arunachal Pradesh	E. Himalayas	83743	68763	103	5.57	1	1	5
Assam	E. Himalayas	78438	26058	102	5.51	2	2	6
Meghalaya	E. Himalayas	22429	15690	70	3.78	3	4	7

Sources: $Singh (1980)[90]; Singh & Sinha (1994)[91]; $Upreti (1998)[81]; *The state of forest report* (1989)[102]
*G.P. Sinha, BSI, Sikkim, personal communication.
#1989 assessment includes forests having over 10% crown cover [102]

values of lichen diversity are presented in Table III. While the forest cover is more or less expectedly consistent with the land areas, the number of lichen species seems to be inconsistent. Sikkim has the smallest area amongst the counterparts but ranks third in terms of lichen diversity, whereas Arunachal Pradesh as the largest state with very dense forest cover secures a low fifth rank. Similarly, Nagaland ranking fifth in area commensurating with its forest cover emerges as the richest amongst the six other counterparts. These patterns seem to be an artifact of the levels of lichen surveys conducted in these states. However, the investigators of these sources have not attempted even qualitatively, if not quantitatively, to assess the efforts put in these states except claiming to have conducted exhaustive surveys that have not stated measure or methodology. This has caused difficulty in assessing the efforts put, except to relate the overall areas and the forest covers that brought out the apparent inconsistencies. Future surveys therefore need to be objective oriented and methodological.

5. Landscape-level patterns

Locality-specific landscape areas ranging between nearly 1 and 700 sq. km and numbers of lichen species for 10 exhaustively surveyed localities with their sources of information are presented in Table IV. At least three localities, viz. Palani Hills, Corbett National Park and Bangalore are worth noticing, others having proportionate numbers of species to their respective areas. However, except for the western parts of Nanda Devi Biosphere Reserve (WNDBR) and Chopta-Tunganath[74], the available information does not allow us to draw the species-area curves to assess the completeness of the total species in these localities. Assuming that the stated exhaustive surveys to be equivalent of the saturation of the species for the given locality, Palani Hills from South India emerges as the richest locality as compared to the other nine, whereas Bangalore and Corbett National Park in relation to their areas rank very low for the lichen species richness. Interestingly, a very similar pattern is seen for these localities with the addition of two more, viz. Gangotri and Mussoorie Hills with respect to the diversity of species of macrolichens (Table V). Low diversity may be attributed to air pollution in Bangalore and land degradation in the Corbett Park. Notably enough, most of the exhaustively surveyed localities < 700 sq. km. are concentrated in the W. Himalayas with only three localities from the

Table IV
Species diversity levels of lichens from 10 exhaustively surveyed localities in India

Locality name	Lichen region to which it belongs	Lat.–Long.	Area (sq. km)	Number of species	% of Total of India	Ranks based on		Source
						Area	Species	
Palani Hills	W. Ghats	10°4'–10°28' N 77°19'–77°52' E	126.84	318	17.19	8	1	Singh[106]
Pindari Valley*#	W. Himalayas	30°15.30" N 80°2.0" E	700	122	6.59	1	2	Awasthi[107]
Chopta–Tunganath	W. Himalayas	30°20'–30°35' N 79°10'–79°20' E	500	92	4.97	4	3	Upreti & Negi[108]
WNDBR$	W. Himalayas	30°30'–30°40' N 79°44'–79°58' E	500	87	4.70	3	4	Upreti & Negi[109]
Sikkim-Darjeeling	E. Himalayas	27° N and 87°15" E	NA	80	4.32	NA	5	Chopra[103]
Corbett N. Park	Foothills of W. Himalayas	29°13'–29°35' N 78°46'–79°33' E	520.82	69	3.73	2	6	Upreti & Chatterjee[110]
Chakrata hills*#	W. Himalayas	30°32" N and 77°54" E	200	64	3.46	6	7	Awasthi & Joshi[111]
Kashmir Valley*	W. Himalayas	32°17' –36°38' N 73°26' – 80°30' E	150	43	2.32	7	8	Awasthi & Singh[112]
Bangalore#	W. Ghats	12°8' N and 77°37' E	300	30	1.62	5	9	Sanjeev & Negi Unpublished
Lalbagh,*# Bangalore	W. Ghats	12°8' N and 77°37' E	0.972	22	1.19	10	10	Awasthi & Upreti[113]
Rumbak Valley, Ladak	W. Himalayas	34° N and 72° 30' E	100	21	1.14	9	11	Negi & Upreti[74]

*Lat.-long. and areas are not given in the sources cited.
Lat-long. and areas are approximated.
$ Western part of Nanda Devi Biosphere Reserve, area and lat.-long. corrected from Negi.[74]

Western Ghats. This further substantiates the incompleteness of the information for the regional level assessment.

6. Ecological patterns

While more than five decades of systematic studies have accumulated taxonomic information of the 2021 species of lichen flora, of India, only very recently have ecologists begun to investigate their community ecology.[69, 74a, b] Some of the questions posed during the investigation include: how diversity of macrolichen taxa changes across different macrohabitats (ecological units categorized based on the dominant vegetation component) and microhabitats (major substrates as rock, soil and wood) within a landscape? Does this diversity of macrolichens go hand in hand with other taxa such as mosses and woody plants? If so, what are the biodiversity monitoring and conservation implications? How emerging patterns can be linked to the bioresource conservation policy measures and their implementation? For example, in two localities, viz. WNDBR and Chopta-Tunganath, an area of about 500 sq. km in the Garhwal Himalayas, temperate coniferous and mixed Oak–coniferous forests emerged as the richest for lichen species as compared to other macrohabitats such as alpine meadows and Birch-Rhododendron forests in the region (Fig. 2). On the other hand, wood substrates appeared to

Table V
Macrolichen species diversity levels from 12 exhaustively surveyed localities in India

Locality name	Lichen zone to which it belongs	Lat.-Long.	Area (sq. km)	Number of species	% Total of India	Ranks based on		Source
						Area	Species	
Palani Hills	W. Ghats	10°4'–10°28' N 77°19'–77°52' E	126.84	191	27.29	9	1	Singh[106]
Pindari Valley*#	W. Himalayas	30°15.30" N 80°2.0" E	700	100	14.29	1	2	Awasthi[107]
Chopta–Tunganath	W. Himalayas	30°20'–30°35' N 79°10'–79°20' E	500	85	12.14	4	3	Upreti & Negi[108]
WNDBR$	W. Himalayas	30°30'–30°40' N 79°44'–79°58' E	500	76	10.86	3	4	Upreti & Negi[109]
Gangotri & Gomukh*#	W. Himalayas	30° 15' N and 79° 30' E	250	60	8.57	6	5	Awasthi & Singh[114]
Chakrata Hills*#	W. Himalayas	30°32" N and 77°54" E	200	50	7.14	7	6	Awasthi & Joshi[111]
Mussoorie Hills	W. Himalayas	30° 27' N and 78° 06' E	30	35	5.00	11	7	Awasthi & Joshi[115]
Kashmir Valley*	W. Himalayas	32°17' – 36°38' N 73°26' – 80°30' E	150	29	4.14	8	8	Awasthi & Singh[112]
Rumbak Valley, Ladakh	W. Himalayas	34° N and 72° 30' E	100	18	2.57	10	9	Negi & Upreti[74c]
Lalbagh, Bangalore*#	W. Ghats	12°8' N and 77°37' E	0.972	14	2.00	12	10	Awasthi & Upreti[113]
Bangalore#	W. Ghats	12°8' N and 77°37' E	300	11	1.57	5	11	Sanjeev & Negi Unpublished
Corbett N. Park	Foothills of W. Himalayas	29°13' – 29°35' N 78°46' – 79°33' E	520.82	7	1.00	2	12	Upreti & Chatterjee[110]

*Lat.-long. and areas are not given in the sources cited.
#Lat-long and areas are approximated.
$Western part of Nanda Devi Biosphere Reserve, area and lat.-long. corrected from Negi.[74]

support highest number of lichen species as compared to soil and rocks in the landscape consisted of a mosaic of macrohabitats (Fig. 3). Notably, species diversity of macrolichens go hand in hand with mosses as well as woody plants.[74] This finding supports the importance of surrogates to be employed for cost- and time-effective assessments and the monitoring of biodiversity.[92, 93] The study objectively measures composite conservation value of the habitats (macrohabitats) after quantitatively assigning numerical values to the species of that habitat based on rarity, geographical range, taxonomic distinctiveness and local average abundance. Pitching on this criteria, alpine meadows ranked not only very close to other counterparts in the landscape with respect to their composite conservation value but also significantly harbored geographically narrow niched and taxonomically more distinct species. Prevailing inconsistencies in the ecological units with respect to a number of community attributes such as diversity and conservation value, strengthen the notion of management of a mosaic of habitats rather than selecting out only a few protected areas or say a forest patch in a locality for conservation and sustainable development. The studies also demonstrate the nonlinear relationship

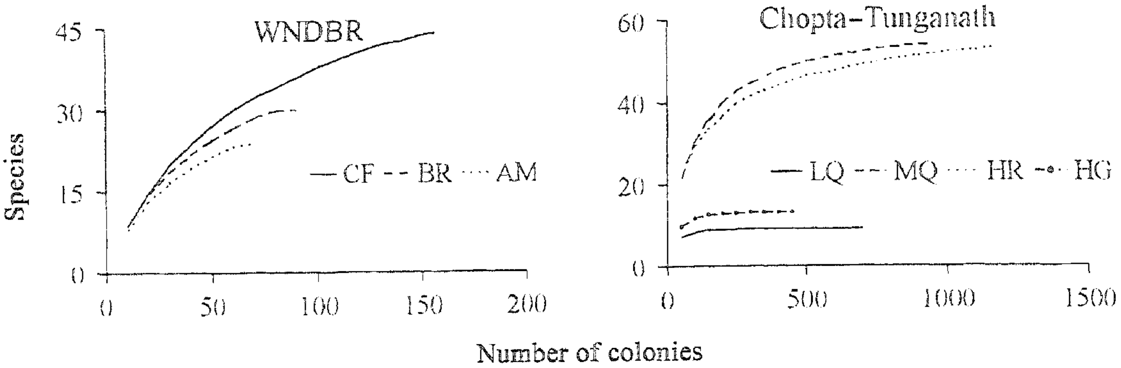

FIG. 2. Accumulation of species of macrolichens with increasing number of colonies in different macrohabitat types from WNDBR and Chopta–Tunganath in Garhwal Himalayas. The macrohabitat types are: CF; Coniferous forest (2500–3400 m), BR; Birch–Rhododendron forest (3400–3700 m), AM; Alpine meadow (3800–4500 m) from WNDBR and LQ; lower altitude Quercus forest (1500 m), MQ; middle altitude Quercus forest (2500–2800 m), HR; high altitude Rhododendron forest (2900–3200 m), HG; higher altitude grassland (3400–3700 m) from Chopta–Tunganath. The numbers of species at each interval is an average of 100 simulations.

of lichen diversity and altitude in at least two localities from the Himalayas, contrary to the linearly decreasing diversity with altitude in many groups such as birds, woody plants and amphibians[74c, 94–96] (Fig. 4). How and to what extent locally dominant land uses such as fuel wood collection, livestock grazing, fire and tourism affect the patterns? Such questions need further research and require periodic monitoring techniques. Although we are very far from understanding the processes governing these patterns, accumulation of such locality-specific knowledge may help developing objectively conservation and management policies and their implementation on the ground.

7. Forests and lichens

Woody components of forest ecosystems provide a major substrate contributing over 65% species of the lichen communities in the landscapes such as Chopta–Tunganath and the WNDBR[74] (Fig. 5). Forests play a vital role structuring these communities and are often considered as 'hot spots' of epiphytic lichens.[92, 97, 98] These 'hot spots' in India have dwindled with a series of British colonial exploitative policies and continue to degrade under post-colonial complex

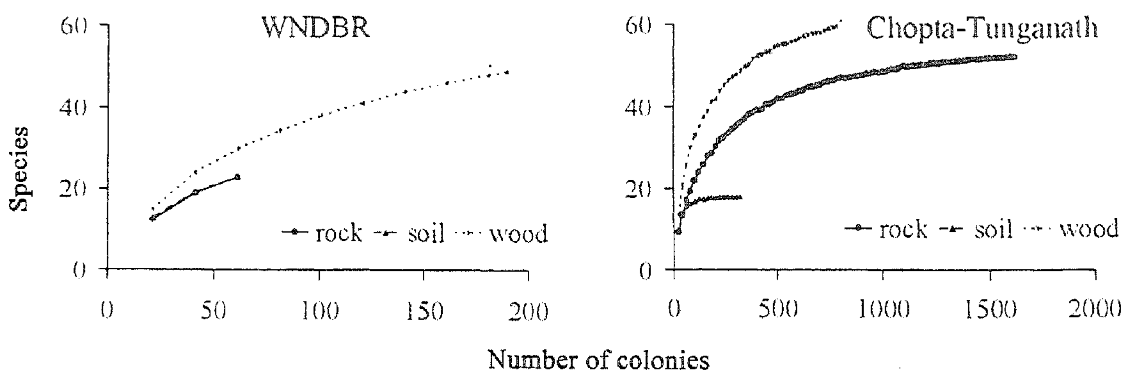

FIG. 3. Accumulation of species of macrolichens with increasing number of colonies in three different microhabitats, viz. rock, soil and wood from WNDBR and Chopta–Tunganath.The numbers of species at each interval is an average of 100 simulations.

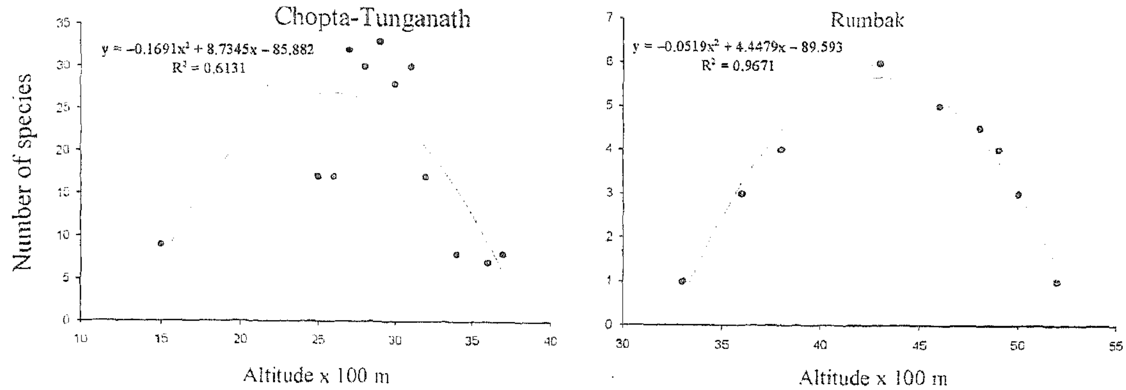

FIG. 4. Relationship between elevation gradient and number of macrolichen species from Rumbak Valley in Ladakh and Chopta–Tunganath in the Garhwal Himalayas.

processes of degradation with alarming deforestation rates of as high as 1.5 million hectares per year.[99, 100] India's burgeoning human population of over one billion with its continued growth rate of 2.1% per year appears to have even more adverse impact on the forests. Despite resurgence of community participation and recognition of traditional management practices, particularly after the failures of capitalistic foreign investments to control the problems of deforestation in India, complex processes of degradation including lack of management control with dominant centralized and often corrupt bureaucracy still prevails in country's forest management regime.[101] While 2000 years ago, as much as 85% of the Indian subcontinent was reportedly covered with forests, actual signs of deforestation surfaced only after 1770 AD when the forests were viewed as an asset of the state with great commercial potential. Overexploitation of this asset gradually reduced forest cover to only 19.5 % (with over 10% crown cover) by the end of 1987, contrasting with the standing national goal of keeping one-third of the landmass under forests.[102, 103] Although no quantitative estimation of the actual losses to the lichen communities associated with the deforestation are available, given their vital integrity with the forests, hundreds of species might have already vanished much before Nylender[82] made his first observations on the Himalayan lichens. Many of the wood-loving species might have been lost forever with huge quantities of logs felled for railway cross-ties during the 1890s, much before Chopra[104] and his team explored the lichen flora in India.

8. Conservation problems and prospects

Monitoring of presently known species, a little over 2000, and documenting another 200 to 5000 undescribed species of lichen assemblage spreading over 328 million hectares of Indian landmass will continue to be one of the biggest challenges of the new millennium. Notably enough, 60% of the lichens recorded so far are crustose forms, most of which have only one time record in the whole history of more than six decades of lichenology in India.[80] Moreover, these crustose forms are very difficult to collect and identify, and are more likely to be overlooked in the field even by expert lichenologists. This is evidenced from Singh and Sinha's[91] exhaustive surveys in Nagaland, where they could enlist only 139 species of microlichens as opposed to 209 species of macrolichens. Given the taxonomic difficulties and the poor scenario in the country, I speculate that the bulk of the unrecorded species would be microlichens which may remain undescribed and unidentified for many years to come.

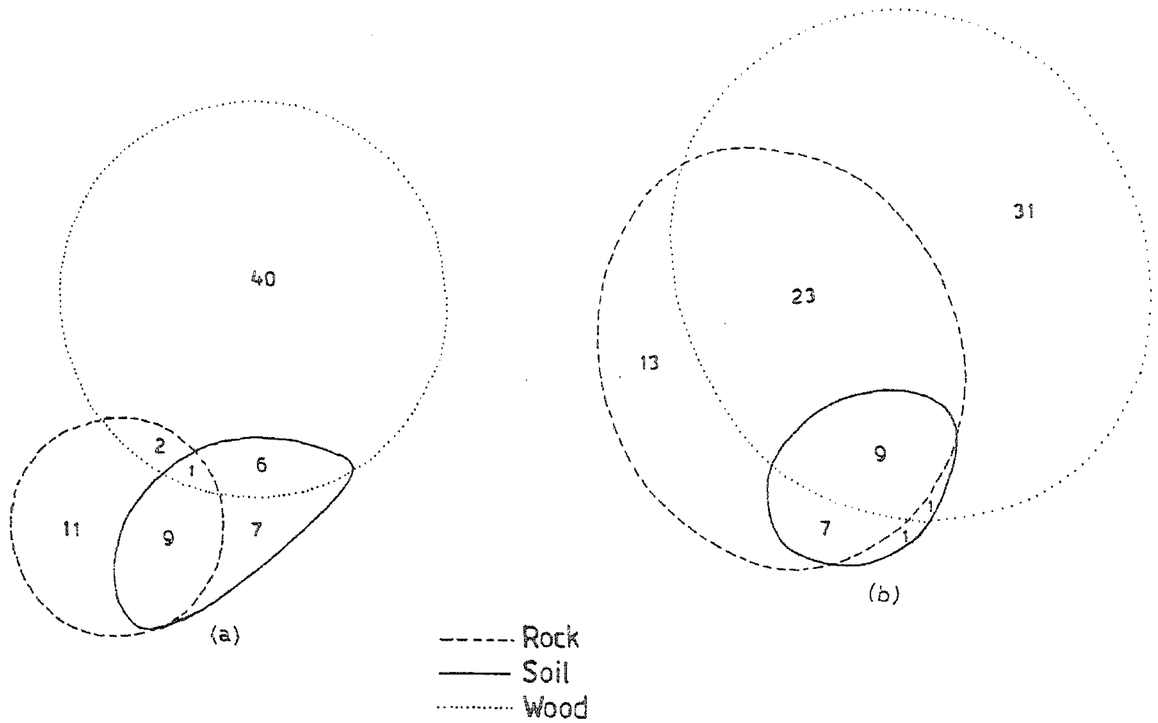

FIG. 5. Distribution of (a) 76 and (b) 85 species of macrolichens in three substrates, viz. rock, soil and wood from (a) Nanda Devi Biosphere Reserve and (b) Chopta–Tunganath landscapes in the Garhwal Himalayas.

While a number of factors such as urbanization, commercial overexploitation, forest fires and grazing, deforestation and unsystematic forestry practices have been identified as major threats to the lichen flora of India, hardly any efforts have gone to measure and monitor the extent of actual impact of these land use changes on the lichen abundance and diversity[68, 74a, c, 80]. India as a mega-diverse country supporting over a billion people distributed in 2600 distinct ethnic communities with varied resource use patterns should therefore be prepared to face this immense task 'strategically'. This can be undertaken by organizing conservation science activities through linking a cross-section of people; not just taxonomists, ecologists, computer wizards and social scientists but also tribals, traditional healers and innovators; not only government research institutions such as the Council of Scientific and Industrial Research (CSIR), Botanical Survey of India (BSI), Zoological Survey of India (ZSI) and the Indian Institute of Science (IISc), but also academic and private institutions like schools, colleges and non-governmental organizations (NGOs). Lichens have so far been projected more as pollution indicators with little economic importance overshadowing their ecological and functional roles in the ecosystem. We need to make the subject informative, easy and accessible creating proper awareness through both oral and with written material preferably in the regional languages as well.[48] For this we need to first develop techniques of rapid surveys coupled with targeting indicator taxa to be used for assessing the diversity in new areas.[74] Production of keys and literature in regional languages will help the local people to estimate at least the macrolichen diversity which in turn may facilitate locating the areas for promoting *in situ* conservation activities.

Conserving India's remaining 60 million hectares of natural forests supporting thousands of lichen species is of immense importance. More than 54 million tribals rely heavily on these forests in addition to nearly 350 million people partially dependent on them. Yet 95% of the forest area is under government ownership. Ironically, poverty prevails in these biologically rich forested areas of the country. While community-based biodiversity-related traditional knowledge systems are gaining recognition all over the world, only a very few ethnolichenological studies have been carried out in the country. Encouraging local communities as able forest keepers and prudent bioresource users would facilitate linking biodiversity science from scientific intellectuals to the grassroot resource managers and *vice versa*.

9. Conclusions

While more than six decades of active research on lichen taxonomy in this part of the world has contributed to over 10% of the 20,000 species recorded in the world so far, there has been no monitoring of this documented biodiversity. None of the taxonomic experts in the country has attempted to keep record of repeatable efforts put in any form while documenting the lichen flora. This has caused a great difficulty in assessing the quality of the data and levels of diversity at different spatial scales. However, in the second half of the last decade of the 20th century, ecological explorations have paid attention to methodological and more objective ways of documenting the lichen flora along with several other taxa. More such studies need to be carried out at on a war footing in manageably locality-specific landscapes across different biogeographic regions, the scales at which conservation measures are often operationalized.[74, 105] This will further facilitate interdisciplinary biodiversity research incorporating a combination of different sets of organisms at different time and spatial scales. Given the most heterogeneously expanding human population of India and its heavy reliance on biodiversity, proper periodic assessment of the biological resources including the lichens and monitoring of their responses to the area, specific land use changes with greater participation of local communities are urgently required.

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