Chapter 3
Terricolous Lichens in Himalayas: Patterns of Species Richness Along Elevation Gradient

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1 Introduction

Lichens are the primary colonizers of the home planet along with non-lichenized fungi, algae, bacteria, cyanobacteria, and mosses. Diverse morphological growth forms and tolerant physiology provide lichens an edge over other cryptogams, enabling them to colonize nearly all of the terrestrial habitats of our planet. Terricolous lichens (highly sensitive) are important subsets of lichen community, as they highly sensitive to climatic, topographic, and anthropogenic factors (Will-Wolf et al. 2002). Terricolous lichens along with cyanobacteria, algae, microfungi, and bryophytes (in different proportions) sometimes constitute an intimate functional entity referred to as biological soil crusts (BSCs) (Belnap et al. 2001a). The biological soil crust is the heterogeneous material that forms after colonization, nutrient enrichment, and stabilization of the soil lichens (Eldridge 1996). BSCs impart spatial and temporal patterns at different scales determining biological diversity that begins from harsh to congenial environments of any stages of succession. Terricolous lichen diversity in BSCs is closely associated with habitat characteristics, and therefore indicates the health of ecosystem (Pellant et al. 2001).

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2 Terricolous Lichens: Role in Ecosystem Services

Terricolous lichens by virtue of their requirement of greater environmental stability are highly sensitive indicators of the overall ecosystem functioning and various environmental disturbances (Eldridge and Tozer 1997; Grabherr 1982; Scutari et al. 2004; Lalley and Viles 2005; Motiejûnaitë and Wiesùaw 2005; Lalley et al. 2006a; Clair et al. 2007; Rai et al. 2011, 2012). The ecological and geomorphic importance of terricolous lichen communities are related to the soil crust they inhabit. Terricolous lichens are known to be sources of nitrogen and carbon fixation (Beymer Klopatek 1992; Evans and Belnap 1999; Harper and Belnap 2001), vital soil stabilizers (Belnap and Gillette 1998; Eldridge 1998; Eldridge and Leys 2003), and providers of habitat and food sources for other organisms (Zaady and Bouskila 2002; Lalley et al. 2006b), and are known to influence growth of associated cryptogamic soil vegetation (Lawrey 1977; Gardner and Mueller 1981; Sedia and Ehrenfeld 2005; Escurado et al. 2007; Lawrey 2009; Favero-Longo and Piervittori 2010). Terricolous lichen-dominated BSCs are an indicator of physical, physiological, and chemical impacts after grazing, trampling, climate change, and pollution (Belnap and Eldridge 2001; Belnap et al. 2001a, b).

3 Terricolous Lichens in the Himalayas

Himalayan habitats show diversity both in climate and habitat conditions, where they are more moist in the eastern Himalayan alpine shrubs and meadows, which act as a transit into drier central Tibetan plateau alpine steppe of central Tibet in the north. The stressed climate (i.e., higher environmental lapse rate, high wind velocity, high UV radiation, low atmospheric pressure, and low precipitation), and the delimiting nutrient and exposure regime of Himalayas, support relatively simple ecosystems, characterized by limited trophic levels and relatively, very few plant growth forms and species (Rai et al. 2010). Despite these constrains, alpine habitats of the Himalayas harbor some of the unique biodiversities of the region, which are vital for the overall ecosystem functioning and stability. Himalayan habitats are rich in lichen biodiversity, which constitute a substantial amount of cryptogamic ground vegetation (Upreti 1998). Major distribution of Terricolous lichens in the Himalayas ranges from temperate (1,500–3,000 m) to alpine (> 3,000 m) habitats (Baniya et al. 2010; Rai et al. 2011). Altitudinal distribution patterns of terricolous lichens of the Himalayan region are addressed in few region-specific lichenological investigations (Pinokiyo et al. 2008; Baniya et al. 2010; Huang 2010; Rai et al. 2012).

4 Objectives

The present work has been undertaken to elucidate an elevational richness pattern of the Himalayan terricolous lichens with reference to (i) mid-dominance peak of terricolous lichen diversity along the gradient; (ii) dominant terricolous lichen families that follow a similar richness pattern, and (iii) probable determining factors to explain each of these patterns.

5 Materials and Methods

5.1 Study Area

The Himalayas are the youngest fragile mountains of Cenozoic origin. Present vegetation is believed to be the Pleistocene formation established after Miocene orogeny (Singh and Singh 1987). The Himalayas arch the massive Indian subcontinent including Nepal, India, Burma, Bhutan, and Sri Lanka, which leaves the Tibetan plateau on the backside. The Himalayan range is about 2,500 km long and passes all the way from Burma in the east to Afghanistan in the west. The Himalayas lie between 84°E and 84°W longitude (Singh and Singh 1987). It is the confluent of Austro-Polynesian, Malayo-Burman, Sino-Tibetan, Euro-Mediterranean, and African elements. These topographies with environment are believed to be suitable to all these flora and fauna since ancient history. Soil lichens collected, described, deposited, and published mainly from the Himalayan region of India and Nepal are considered here.

The Himalayas comprise the longest and a continuous bioclimatic region of the world. The elevation of the landscape varies from the sea level to the world's highest peak, i.e., the Mount Everest, 8,848 m above sea level, within a short horizontal distance. Diverse topographies also harbor diverse vegetation typical of hot, wet tropics to nival zones of the world. Hot and humid climates are characteristic features of landscapes toward lower altitudes that slowly decrease with increasing altitude. Thus, temperature and precipitation are two major gradients. Similarly, intensity of precipitation varies differently along the Himalayas. Monsoon is the main source of rainfall that begins from the Bay of Bengal and ends in the western Himalayas. The eastern Himalayas, nearer to the Bay of Bengal, receive more rainfall during summer (May to September). The intensity slowly decreases toward the western Himalayas. Terricolous lichens from the Himalayas have witnessed and are indicators of these changes since prehistory.

5.2 Data Source

The main data source for this study is *A Compendium of the Macrolichens from India, Nepal and Sri Lanka* (Awasthi 2007), the checklist of Nepalese lichens (Sharma 1995; Baniya et al. 2010). Along with the above-mentioned sources, data of *Cladonia* of India and Nepal were supplemented by analysing about 700 specimens lodged in lichen herbarium of the Council of Scientific and Industrial Research (CSIR)-National Botanical Research Institute (LWG). The distribution pattern of soil lichens of Nepal was crosschecked using data from Baniya et al. (2010).

The altitudinal ranges of the Himalayan soil lichens (100–6,000 m) were interpolated after dividing them into 60 bands of 100 m each, and a complete data matrix for all soil lichen species was assembled. Presence of a species indicates that the species occurs in, or has been collected in the past from, that altitudinal band and the absence means either that species does not occur or has previously not been collected from that altitude (Baniya et al. 2010).

A species is assumed to be present at all possible 100-m bands between its upper and lower altitudinal limits as recorded in the dataset. For example, a terricolous lichen *Baeomyces pachypus* that has elevational occurrences between 1800 to 3600 m in the literature falls between the 1,800- and 3,600-m bands throughout the subcontinent (Baniya et al. 2010). Endemic soil lichen species are encountered at a specific landscape or in a country that counts for all the Himalayas. The lichen species listed in the compendium or literature without any altitude reference were discarded. Such soil lichen species were around 30 in number.

Thus, the species richness that applies here is an estimate of the total number of soil lichen species and/or their family occurring at each 100-m altitudinal band throughout the Himalayas. This corresponds to macroscale study, which is closer to gamma diversity as mentioned by Whittaker (1972).

5.3 Data Analysis

Considering total lichen species richness, patterns related to, six dominant families as response variables and their elevations as a predictor variable were extracted by applying a cubic smooth spline (*s*) with the framework of generalized additive models (GAM) (Hastie and Tibshirani 1990; Heegaard 2004; Baniya et al. 2010). GAM, which is one of the most conservative, local regression methods has been used in this study, without priori. Response variables variables are counts; thus, the variance changes with the mean. Over dispersion in the dataset was corrected through an application of quasi-Poisson family of error, which has a logarithmic link function (Crawley 2006). Normal distribution in the error was tested after the basic Q–Q (quantile–quantity) diagnostic plots against residuals. The change in deviance follows the *F*-distribution. R 2.13.1 was used to analyse the data and smoothers (R Development Core Team 2011). The models were fitted with the library *GAM* (Hastie and Tibshirani 1990).

6 Results

6.1 General Pattern of Species Richness

A total of 212[1] terricolous/soil lichen species, 1.06 % of the total lichens reported from India alone, were found recorded from the Himalayas with altitudinal

[1] The data takes into account representative terricolous specimens lodged in CSIR-NBRI, lichenological herbarium-LWG.

distribution range. These terricolous lichens species belonged to 24 families and 54 genera. Their altitudes ranged from 100 to 6,000 m above sea level. *Cladoniaceae* was the dominant family with 53 species, followed by *Parmeliaceae* with 49 species (Table 3.1).

Total soil lichen species richness showed statistically significant unimodal relation with altitude. The highest number of soil lichen species (89) occurred at 2,400 m (Fig. 3.1; Table 3.2). The soil lichen species richness was found increasing from sea level (100 m) to 2,400 m and declining afterward.

6.2 Mid-Richness Peak of Dominant Families

The most dominant soil lichen families also showed unimodal responses to elevation at different altitudes of their highest richness (Fig. 3.2; Table 3.2). For instance, *Cladoniaceae* with 53 species showed unimodal relation of the highest richness (38 species) at 2,700–2,800 m (Fig. 3.2a; Table 3.2). *Parmeliaceae* with 49 species showed unimodal response with the highest richness (17 species) at 2,100 m (Fig. 3.2b; Table 3.2). *Peltigeraceae* (18 species) humped at 2,800 m by 9 species (Fig. 3.2c; Table 3.2), *Physciaceae* (17 species) humped at 1,700–1,800 m by 10 species (Fig. 3.2d; Table 3.2), *Collemataceae* (12 species) humped at 1,200–1,300 m by 6 species (Fig. 3.2e; Table 3.2), and *Stereocaulaceae* (12 species) humped at 3,500–3,600 m by 7 species (Fig. 3.2f; Table 3.2).

The study has found that 2,400 m is the most preferential altitude for soil lichens among 60 altitudinal bands. At this midaltitude (2,400 m) soil lichen species may be supported by all habitats, microenvironments, edaphic factors, and biogeography as well and vice versa.

7 Discussion

A quantitative analysis of the terricolous lichen community from the Himalayas has revealed that they are significantly greater in number and wider in distribution. These terricolous lichen communities are found distributed at all altitudes from 100 to 6,000 m. Moreover, 2,400 m altitude was the most preferable altitude and has abundant number of terricolous lichen species (Fig. 3.1). Not all lichen families behave the same in terms of appearance of maximum number of species with altitude. Terricolous lichens followed the general trend of elevational declining unimodal species richness pattern at larger spatial scales but differed with elevation of maximum richness. The fundamental reasons explaining for this pattern may share with the general pattern of other species richness but the specific cause would be specific to the terricolous lichen only.

Table 3.1 List of terricolous lichen species found in India and Nepal and their range of altitudinal distribution rank of genera and species

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
1	1	*Cladia aggregata*	1	*Cladoniaceae*	2	53	1,500–3,600	22
2	2	*Cladonia acuminata*		*Cladoniaceae*			2,700–3,750	12
3		*C. amaurocraea*		*Cladoniaceae*			4,000–4,221	3
4		*C. awasthiana*		*Cladoniaceae*			1,500–3,500	21
5		*C. borealis*		*Cladoniaceae*			4,000–4,050	2
6		*C. cariosa*		*Cladoniaceae*			1,603–4,100	26
7		*C. cartilaginea*		*Cladoniaceae*			335–3,900	37
8		*C. ceratophyllina*		*Cladoniaceae*			2,286–3,810	16
9		*C. cervicornis*		*Cladoniaceae*			1,829–2,134	4
10		*C. cfr fenestralis*		*Cladoniaceae*			1,800	1
11		*C. cfr ochrochlora*		*Cladoniaceae*			2,100	1
12		*C. chlorophaea*		*Cladoniaceae*			1,500–4,425	30
13		*C. coccifera*		*Cladoniaceae*			2,010–4,420	25
14		*C. coniocraea*		*Cladoniaceae*			1,250–3,600	24
15		*C. corniculata*		*Cladoniaceae*			950–4,600	37
16		*C. corymbescens*		*Cladoniaceae*			1,100–4,420	34
17		*C. crispata var. cetrariiformis*		*Cladoniaceae*			3,250	1
18		*C. delavayi*		*Cladoniaceae*			1,618–4,250	28
19		*C. didyma*		*Cladoniaceae*			1,350–3,300	20
20		*C. farinacea*		*Cladoniaceae*			2,000–2,286	4
21		*C. fenestralis*		*Cladoniaceae*			50–4,724	47
22		*C. fimbriata*		*Cladoniaceae*			1,585–4,500	30
23		*C. fruticulosa*		*Cladoniaceae*			795–3,962	33
24		*C. furcata*		*Cladoniaceae*			560–4,250	38

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/family	No. of spp./family	Altitudinal range (m)	Frequency
25		*C. humilis*		*Cladoniaceae*			2,250–2,850	7
26		*C. indica*		*Cladoniaceae*			350–700	4
27		*C. laii*		*Cladoniaceae*			2,700–3,900	13
28		*C. luteoalba*		*Cladoniaceae*			2,800–3,658	10
29		*C. macilenta*		*Cladoniaceae*			1,200–3,962	29
30		*C. macroceras*		*Cladoniaceae*			4,200	1
31		*C. macroptera*		*Cladoniaceae*			50–4,176	42
32		*C. mauritiana*		*Cladoniaceae*			609–2,750	23
33		*C. mongolica*		*Cladoniaceae*			1,615–3,750	23
34		*C. nitida*		*Cladoniaceae*			4,176	1
35		*C. ochrochlora*		*Cladoniaceae*			7,00–4,000	34
36		*C. pocillum*		*Cladoniaceae*			1,500–4,700	33
37		*C. praetermissa*		*Cladoniaceae*			1,505–1,550	2
38		*C. pyxidata*		*Cladoniaceae*			1,200–4,600	35
39		*C. ramulosa*		*Cladoniaceae*			1,050–4,000	30
40		*C. rangiferina*		*Cladoniaceae*			1,600–4,481	30
41		*C. rei*		*Cladoniaceae*			2,200–3,200	11
42		*C. scabriuscula*		*Cladoniaceae*			3,34–3,962	38
43		*C. sinensis*		*Cladoniaceae*			2,200	1
44		*C. singhii*		*Cladoniaceae*			1,200–3,048	20
45		*C. squamosa*		*Cladoniaceae*			1,000–4,221	33
46		*C. stricta*		*Cladoniaceae*			3,300–4,420	12
47		*C. subconistea*		*Cladoniaceae*			795–1,875	12
48		*C. subradiata*		*Cladoniaceae*			1,379–3,800	25

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
49		*C. subsquamosa*		*Cladoniaceae*			1,295–2,567	14
50		*C. subulata*		*Cladoniaceae*			2,100–3,000	10
51		*C. turgida*		*Cladoniaceae*			2,210	1
52		*C. verticillata*		*Cladoniaceae*			1,000–4,100	32
53		*C. yunnana*		*Cladoniaceae*			1,800–3,963	23
54	3	*Allocetraria ambigua*	2	*Parmeliaceae*	18	49	4,875	1
55		*A. flavonigrescens*		*Parmeliaceae*			4,600–4,800	3
56		*A. sinensis*		*Parmeliaceae*			4,830	1
57		*A. stracheyi*		*Parmeliaceae*			3,000–5,000	21
58	4	*Bryoria bicolor*		*Parmeliaceae*			1,500–3,600	22
59		*B. implexa*		*Parmeliaceae*			3,700–4,000	4
60		*B. smithii*		*Parmeliaceae*			2,400–4,500	22
61		*B. tenuis*		*Parmeliaceae*			2,250–3,650	15
62	5	*Bulbothrix isidiza*		*Parmeliaceae*			800–1,500	8
63		*B. meizospora*		*Parmeliaceae*			1,500–2,250	9
64	6	*Canomaculina subtinctoria*		*Parmeliaceae*			450–2,500	21
65	7	*Cetraria aculeata*		*Parmeliaceae*			4,000	1
66		*C. islandica*		*Parmeliaceae*			3,450–4,500	11
67		*C. muricata*		*Parmeliaceae*			4,000	1
68		*C. nepalensis*		*Parmeliaceae*			4,500	1
69		*C. nepalensis*		*Parmeliaceae*			4,500	1
70		*C. nigricans*		*Parmeliaceae*			3,800	1
71	8	*Evernia mesomorpha*		*Parmeliaceae*			2,500–3,600	12
72	9	*Everniastrum cirrhatum*		*Parmeliaceae*			1,400–3600	23

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
73		*E. nepalense*		*Parmeliaceae*			1,300–4,200	30
74		*E. vexans*		*Parmeliaceae*			1,200–2,250	12
75	10	*Flavocetraria cucullata*		*Parmeliaceae*			3,600–4,500	10
76		*F. nivalis*		*Parmeliaceae*			3,800–4,500	8
77	11	*Flavocetrariella leucostigma*		*Parmeliaceae*			3,900–4,500	7
78		*F. melaloma*		*Parmeliaceae*			3,900–4,200	4
79	12	*Flavoparmelia caperata*		*Parmeliaceae*			1,600–3,500	20
80	13	*Hypogymnia delavayi*		*Parmeliaceae*			3,400–5,600	23
81		*H. fragillima*		*Parmeliaceae*			3,400–3,780	5
82		*H. hypotrypa*		*Parmeliaceae*			3,600–4,050	6
83		*H. physodes*		*Parmeliaceae*			2,200–2,700	6
84	14	*Hypotrachyna exsecta*		*Parmeliaceae*			1,800–2,300	4
85		*H. koyaensis*		*Parmeliaceae*			1,500–2,100	7
86	15	*Lethariella cladonioides*		*Parmeliaceae*			3,600–5,400	19
87		*L. cladonioides*		*Parmeliaceae*			4,724	1
88	16	*Melanelia hepatizon*		*Parmeliaceae*			3,600	1
89		*M. stygia*		*Parmeliaceae*			3,300–3,600	4
90	17	*Melanelixia fuliginosa*		*Parmeliaceae*			1,500–2,500	11
91		*M. villosella*		*Parmeliaceae*			2,400–3,300	10
92	18	*Parmelinella wallichiana*		*Parmeliaceae*			500–3,000	26
93	19	*Parmotrema crinitum*		*Parmeliaceae*			1,300–2,250	11
94		*P. grayanum*		*Parmeliaceae*			900–2,400	16
95		*P. mellissii*		*Parmeliaceae*			850–2,200	14

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
96		*P. nilgherrense*		*Parmeliaceae*			1,500–4,200	28
97		*P. pseudocrinitum*		*Parmeliaceae*			950–2,100	12
98		*P. pseudonilgherrense*		*Parmeliaceae*			1,600–3,500	20
99		*P. reticulatum*		*Parmeliaceae*			1,500–2,500	11
100		*P. sancti-angelii*		*Parmeliaceae*			1,410–2,100	8
101	20	*Xanthoparmelia bellatula*		*Parmeliaceae*			3,150–3,250	2
102		*X. terricola*		*Parmeliaceae*			3,900–4,500	7
103	21	*Peltigera canina*	3	*Peltigeraceae*	2	18	1,800–3,500	18
104		*P. collina*		*Peltigeraceae*			1,350–1,880	6
105		*P. didactyla*		*Peltigeraceae*			2,000–2,200	3
106		*P. dolichorrhiza*		*Peltigeraceae*			1,600–4,000	25
107		*P. dolichospora*		*Peltigeraceae*			3,000–4,100	12
108		*P. elisabethae*		*Peltigeraceae*			1,350	1
109		*P. horizontalis*		*Peltigeraceae*			2,400–3,450	12
110		*P. leucophlebia*		*Peltigeraceae*			3,800	1
111		*P. malacea*		*Peltigeraceae*			2,100–4,200	22
112		*P. membranacea*		*Peltigeraceae*			1,900–2,400	6
113		*P. polydactylon*		*Peltigeraceae*			1,950–2,920	10
114		*P. polydactylon var. polydatylon*		*Peltigeraceae*			1,950–3,480	16
115		*P. praetextata*		*Peltigeraceae*			1,950–3,600	17
116		*P. pruinosa*		*Peltigeraceae*			1,800	1
117		*P. rufescens*		*Peltigeraceae*			3,000–3,600	7
118		*P. venosa*		*Peltigeraceae*			2,100	1
119	22	*Solorina bispora*		*Peltigeraceae*			3,600–4,200	7

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
120		*S. simensis*		*Peltigeraceae*			1,800–3,300	16
121	23	*Anaptychia pseudoroemeri*	4	*Physciaceae*	7	17	3,780	1
122	24	*Awasthia melanotricha*		*Physciaceae*			4,350–4,510	2
123	25	*Diploicia canescens*		*Physciaceae*			4,650	1
124	26	*Heterodermia boryi*		*Physciaceae*			1,500–3,000	16
125		*H. diademata*		*Physciaceae*			1,200–3,000	19
126		*H. firmula*		*Physciaceae*			1,200–2,200	11
127		*H. hypocaesia*		*Physciaceae*			800–2,500	18
128		*H. japonica*		*Physciaceae*			800–1,500	8
129		*H. leucomelos*		*Physciaceae*			800–1,500	8
130		*H. obscurata*		*Physciaceae*			800–2,500	18
131		*H. pseudospeciosa*		*Physciaceae*			800–2,500	18
132		*H. tremulans*		*Physciaceae*			800–1,500	8
133	27	*Phaeophyscia ciliata*		*Physciaceae*			1,800–3,500	18
134		*P. constipata*		*Physciaceae*			3,500	1
135	28	*Physcia adscendens*		*Physciaceae*			1,500–3,600	22
136		*P. tribacoides*		*Physciaceae*			800–1,500	8
137	29	*Physconia muscigena*		*Physciaceae*			1,500–2,500	11
138	30	*Collema coccophorum*	5	*Collemataceae*	2	12	3,800	1
139		*C. poeltii*		*Collemataceae*			3,900–4,000	2
140		*C. rugosum*		*Collemataceae*			800–2,500	18
141		*C. subflaccidum*		*Collemataceae*			1,500–3,000	16
142	31	*Leptogium arisanense*		*Collemataceae*			2,830	1
143		*L. askotense*		*Collemataceae*			2,330	1

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/family	No. of spp./family	Altitudinal range (m)	Frequency
144		*L. corniculatum*		*Collemataceae*			800–1,500	8
145		*L. cyanescens*		*Collemataceae*			800–1,500	8
146		*L. denticulatum*		*Collemataceae*			800–1,500	8
147		*L. moluccanum*		*Collemataceae*			100–1,500	8
148		*L. platynum*		*Collemataceae*			800–1,500	8
149		*L. trichophorum*		*Collemataceae*			800–1,500	8
150	32	*Stereocaulon coniophyllum*	6	*Stereocaulaceae*	1	12	3,300–3,600	4
151		*S. foliolosum*		*Stereocaulaceae*			2,400–4,000	17
152		*S. foliolosum var. botryophorum*		*Stereocaulaceae*			3,600–3,900	4
153		*S. foliolosum var. strictum*		*Stereocaulaceae*			2,400–3,600	13
154		*S. glareosum*		*Stereocaulaceae*			4,200–4,400	3
155		*S. himalayense*		*Stereocaulaceae*			2,550–5,400	29
156		*S. myriocarpum*		*Stereocaulaceae*			2,700–3,000	4
157		*S. paradoxum*		*Stereocaulaceae*			3,450–3,900	5
158		*S. piluliferum*		*Stereocaulaceae*			1,800–3,900	22
159		*S. pomiferum*		*Stereocaulaceae*			2,500–4,700	23
160		*S. sasaki var. sasaki*		*Stereocaulaceae*			3,600–4,200	7
161		*S. sasakii*		*Stereocaulaceae*			3,600–4,200	7
162	33	*Lobaria isidiosa*	7	*Lobariaceae*	2	9	1,900–3,700	19
163		*L. kurokawae*		*Lobariaceae*			1,800–3,400	17
164		*L. pseudopulmonaria*		*Lobariaceae*			2,550–4,050	16
165		*L. retigera*		*Lobariaceae*			1,600–3,650	22
166	34	*Sticta cyphellulata*		*Lobariaceae*			500–2,100	17
167		*S. limbata*		*Lobariaceae*			1,800–2,420	7

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/ family	No. of spp./ family	Altitudinal range (m)	Frequency
168		*S. nylanderiana*		*Lobariaceae*			1,800–3,600	19
169		*S. orbicularis*		*Lobariaceae*			1,800–2,400	7
170		*S. weigelii*		*Lobariaceae*			8,00–2,250	16
171	35	*Catapyrenium cinereum*	8	*Verrucariaceae*	1	4	4,300–5,080	9
172		*C. cinereum*		*Verrucariaceae*			4,300–5,080	9
173		*C. daedalium*		*Verrucariaceae*			3,900–6,000	22
174	36	*Placidium squamulosum*		*Verrucariaceae*			4,400–4,500	2
175	37	*Lecanora amorpha*	9	*Lecanoraceae*	1	4	5,000	1
176		*L. chondroderma*		*Lecanoraceae*			3,600–5,600	21
177		*L. himalayae*		*Lecanoraceae*			4,000–5,120	12
178		*L. terestiuscula*		*Lecanoraceae*			4,500–5,200	8
179	38	*Leprocaulon arbuscula*	10	*Imperfect fungi*	1	4	2,700–3,100	5
180	39	*Thamnolia vermicularis*		*Imperfect fungi*			5,455	1
181		*T. vermicularis var. subuliformis*		*Imperfect fungi*			3,600–5,400	19
182		*T. vermicularis var. vermicularis*		*Imperfect fungi*			3,600–5,400	19
183	40	*Nephroma expallidum*	11	*Nephromataceae*	1	4	3,000	1
184		*N. helveticum var. helveticum*		*Nephromataceae*			1,600–3,600	21
185		*N. isidiosum*		*Nephromataceae*			3,300–3,500	3
186		*N. parile*		*Nephromataceae*			2,500–3,600	12
187	41	*Baeomyces pachypus*	12	*Baeomycetaceae*	1	3	1,800–3,600	19
188		*B. roseus*		*Baeomycetaceae*			2000–2500	6
189		*B. sorediifer*		*Baeomycetaceae*			2,500	1
190	42	*Coccocarpia erythroxyli*	13	*Coccocarpiaceae*	1	3	2,850	1
191		*C. palmicola*		*Coccocarpiaceae*			800–1,500	8

Table 3.1 (continued)

S. No. (Species)	S. No. (Genera)	Terricolous lichen species	S. No. (Family)	Family	No. of genera/family	No. of spp./family	Altitudinal range (m)	Frequency
192		*C. pellita*		*Coccocarpiaceae*			800–1,500	8
193	43	*Diploschistes muscorum*	14	*Thelotremataceae*	1	3	900–2,160	14
194		*D. muscorum subsp. muscorum*		*Thelotremataceae*			2,160	1
195		*D. nepalensis*		*Thelotremataceae*			900	1
196	44	*Fuscopannaria saltuensis*	15	*Pannariaceae*	2	3	3,100	1
197		*F. siamensis*		*Pannariaceae*			2,400–2,600	3
198	45	*Gymnoderma coccocarpum*		*Pannariaceae*			3,000–3,300	4
199	46	*Ramalina cfr taitensis*	16	*Ramalinaceae*	1	3	1,500–2,500	11
200		*R. hossei*		*Ramalinaceae*			1,200–2,500	14
201		*R. intermedia*		*Ramalinaceae*			3,800	1
202	47	*Dibaeis baeomyces*	17	*Icmadophilaceae*	1	2	1,500–3,600	22
203		*D. sorediata*		*Icmadophilaceae*			2,500	1
204	48	*Siphula ceratites*	18	*Siphulaceae*	1	2	2,500–3,600	12
205		*S. ceratites var. himalayensis*		*Siphulaceae*			4,000	1
206	49	*Usnea maculata*	19	*Usneaceae*	1	2	2,000–2,600	7
207		*U. subfloridana*		*Usneaceae*			2,200–3,700	16
208	50	*Acroscyphus sphaerophoroides*	20	*Caliciaceae*	1	1	4,000–4,400	5
209	51	*Alectoria ochroleuca*	21	*Alectoriaceae*	1	1	4,000–5,100	12
210	52	*Catolechia wahlenbergii*	22	*Rhizocarpaceae*	1	1	4,500	1
211	53	*Mycobilimbia hunana*	23	*Porpidiaceae*	1	1	1,650	1
212	54	*Psora himalayana*	24	*Psoraceae*	1	1	1,200	1

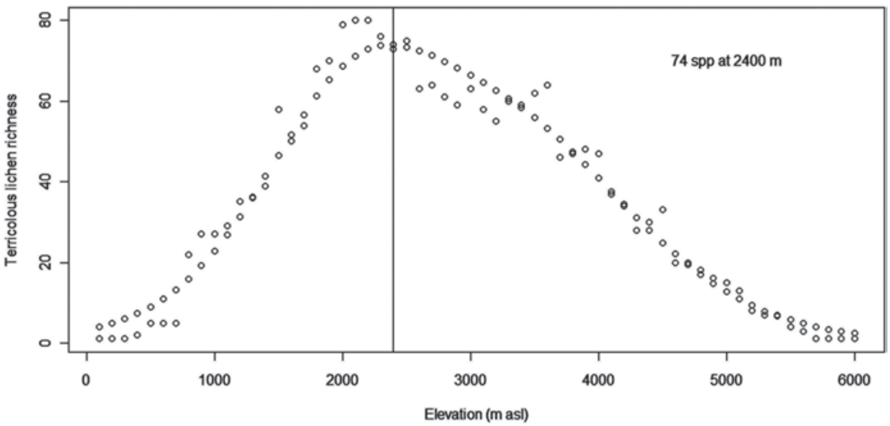

Fig. 3.1 Altitudinal richness pattern of soil lichens. The fitted regression line represents the statistically significant ($P \leq 0.001$) smooth spline (*s*) after using *GAM* with approximately 4 degrees of freedom. The *vertical line* in the space represents the highest richness

Table 3.2 Regression analysis results modelled after different terricolous lichen species richness as well as their six dominant families as response variables and their elevation as predictor variable. The quasi-Poisson family of error fitted in the GAM model after the cubic smooth spline (*s*) with approximately 4 degrees of freedom and the total degrees of freedom in this observation are 59

Response variables	*Resid. df*	*Res. dev*	D^2	*Deviance*	*F*	*Pr* (>*F*)
Total soil lichens	55	57	0.966	1622	448	<0.0001
Cladoniaceae	55	38	0.958	856.7	461.87	<0.0001
Parmeliaceae	55	33.59	0.903	311.67	163.54	<0.0001
Peltigeraceae	55	18.33	0.940	285.5	304.37	<0.0001
Physciaceae	55	40.11	0.864	255	103.72	<0.0001
Collemataceae	55	39.86	0.794	153.78	60.68	<0.0001
Stereocaulaceae	55	13	0.936	190.19	247.07	<0.0001

Resid. df Residual degree of freedom, *Res. dev* Residual Deviance, D^2 Regression coefficient of determination, *F* Fisher value of determination, *Pr* the Probability

The elevation for the highest richness of soil lichens represents the temperate forest zone within the Himalayas. Temperate vegetation occurred at 2,400 m altitude dominated by deciduous tree species such as *Schima-Castanopsis*, laurels, oaks (*Quercus* spp.) and evergreen species such as blue pine (*Pinus wallichiana*). The larger vascular species may provide shade and has relatively higher humidity due to their closed canopy. The climate of this zone is characterized by moderate temperature throughout the whole year and relatively higher precipitation and evapotranspiration than elsewhere. The climatic conditions in the Himalayan temperate habitats help to maintain greater heterogeneity among microhabitats and enough

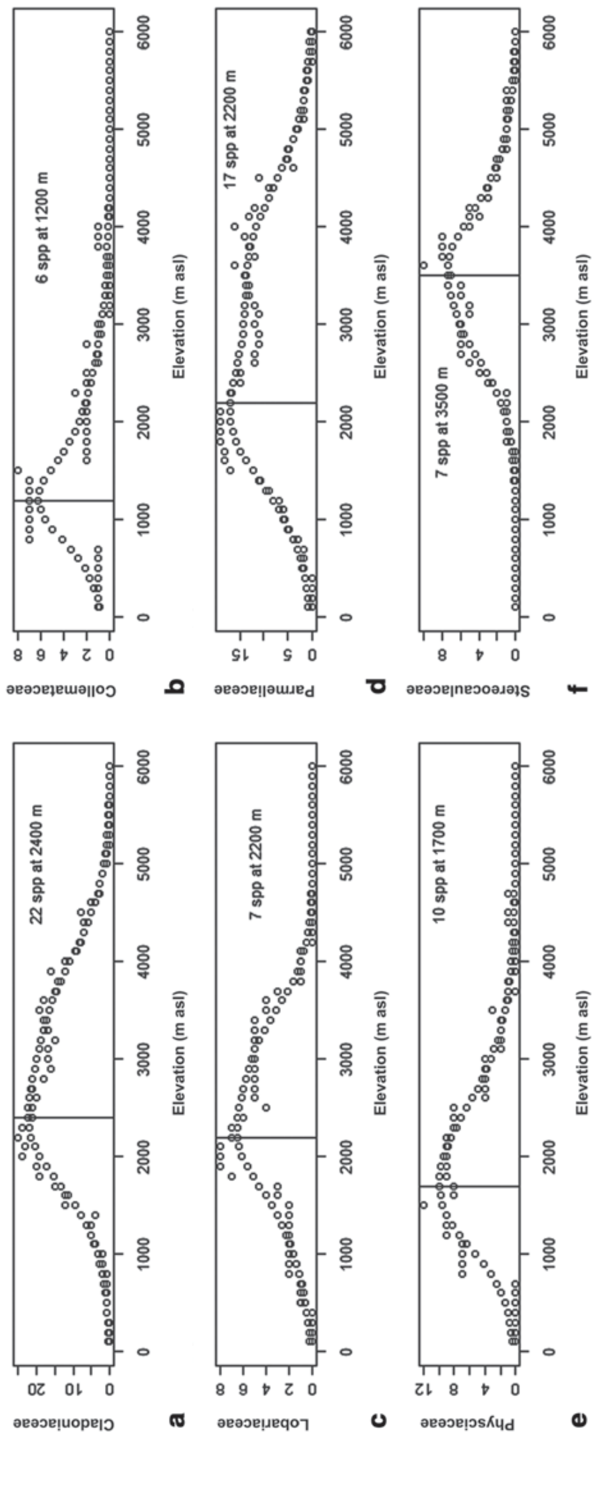

Fig. 3.2 Altitudinal richness pattern showed by dominant soil lichen families. **a** *Cladoniaceae*; **b** *Parmeliaceae*; **c** *Peltigeraceae*; **d** *Physciaceae*; **e** *Collemataceae* and **f** *Stereocaulaceae*. The *fitted regression line* represents the statistically significant ($P \leq 0.001$) smooth spline (s) after using *GAM* with approximately 4 degrees of freedom. The *vertical line* in each figure represents the highest richness

soil moisture which supports good growth of vascular plants and soil lichens. Thus higher soil lichen distribution is expected in these temperate habitats, nurtured by moderate regimes of temperature, precipitation and solar radiation. This view is well supported by development and distribution of soil lichen communities favoured by occurrence of vascular plants in the Great Basin, western USA (Clair et al. 1993). But it differed from the findings of Baniya et al. (2010) and Rai et al. (2011, 2012), which recorded the highest richness from 3,000–3,400 m. These differences may be the result of higher zooanthropogenic perturbations at lower altitudes (≤2,400 m) and consequent shifting of soil lichens to mid-elevations (i.e., 3,000–3,400 m).

Diversity of microhabitats in the form of "doons" and valleys and alpine pastures—*Bugyals* along with a thinning treeline between the altitudinal ranges of 2,000–3,000 m provide ideal conditions for soil lichen communities to develop and flourish. Maximum Bugyals in the Himalayas are situated at average altitude of 2,900–3,400 m, where due to thinning out of treeline, there is least competition with angiospermic vegetation and the harsh climatic regimes (low pressure, high wind velocity, subzero atmospheric temperature, and soil acidity) further increase the probability of soil lichens to colonise, as Himalayan soil lichen species are tolerant to climate extremes (Scheidegger and Clerc 2002). Beside these, majority of Himalayan habitats are now a part of protected area networks, which along with other plant diversity also help soil lichens to colonise and expand.

The number of soil lichens (212) is much higher than earlier studies such as 48 species found in arid and semiarid Australia (Eldridge 1996), 28 species in the northern Namib Desert (Lalley and Viles 2005), 31 species from the southern Namib Desert (Jürgens and Niebel-Lohmann, 1995), 34 species from intermountains of western United States (Clair et al. 1993), 45 species in the Nepal Himalayas (Baniya et al. 2010), and 20 species in Chopta-Tungnath tract in the Garhwal Himalaya (Rai et al. 2011, 2012). The higher species count of soil lichens in Himalayan habitats is due to low competition from other ground vegetation above treeline (≥3000 m), tolerance of specific fruticose/dimorphic terricolous lichens (e.g., *Stereocaulon*, *Cladonia*) to grazing induced trampling and harsh climatic conditions, sufficient hydration of soils throughout the year, tolerance to acidic pH of soil and efficient utilisation of soil macrohabitats (Grabherr 1982; Baniya et al. 2010; Rai et al. 2012; Rai 2012). Change in landuse patterns, anthropogenic pressures, livestock grazing and ground soil cover along with altitudinal gradients are also major factors influencing the terricolous lichen diversity in Himalayas (Rai et al. 2011, 2012).

Anthropogenic pressures, after the increase in human population, is the main controlling driver of nature and its biodiversity on Earth (Ellis and Ramankutty 2008; Ellis 2011). Major concentration of human population can generally be expected at planes or flat areas between the undulating topography of the Himalayas. Dense human population is mostly found in and around the tropical and subtropical range of the Himalayas (i.e., foothills) and less at or above 3,000 m. The anthropogenic pressure arising by commercial aspects of human society has been a major contributor of overall depletion of lichen diversity in Himalayas (Upreti et al. 2005). Many terricolous lichen species (i.e., *Peltigera*, *Thamnolia*, *Cladonia*, *Staereocaulon*) have been exploited as supplementary foods and medicine by different ethnic groups as well as other animals (Saklani and Upreti 1992; Upreti and Negi 1996; Negi 2003; Upreti et al. 2005; Wang et al. 2001).

8 Conclusion

Elevation is the main driver of biological diversity which acts as a composite factor to the anthropogenic pressures, historical location, and higher plant biodiversity. The terricolous lichen diversity in the Himalayas is modulated by natural factors, e.g., climate, topography, soil chemistry, comparative soil cover along altitude, suitable micro habitats, decrease competition; other ground vegetation are also highly guided by zooanthropogenic pressure, e.g., livestock grazing, commercial/ethnic exploitation, tourism etc. Mid-elevation range of 1,200–3,600 m in temperate habitats of the Himalayas are best suitable for soil lichen to make sustainable communities and can be the most suitable thrust area for research in the future.

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