Chapter 2
Distribution Ecology of Soil Crust Lichens in India: A Comparative Assessment with Global Patterns

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1 Introduction

Lichens that occur either directly in soil, sand, peat/humus, or in habitats dominated by soil (e.g., on soil accumulated in rock crevices, on ground in mosses which in turn get rooted to the soil/sand or on degraded plant remains) constitute a unique habitat subset of a lichen community, known as terricolous lichens (Scheidegger and Clerc 2002). Terricolous lichens along with mosses and cyanobacteria form an intimated associative functional entity, often referred to as biological soil crust (BSC). Soil crusts and their component organisms are linked closely to enhanced soil and landscape stability in arid and semiarid areas. It is logical therefore, to view their presence as indicators of good landscape health. In India, both the arid desert in its northwestern part, the grasslands, and steppes from the foothills to the alpine regions in Himalayas contain habitats suitable for growth of terricolous lichens (Rai et al. 2011, 2012).

The Thar desert, in the western state of Rajasthan, is a climatically dry region and experiences frequent droughts. Comparatively the most densely populated desert in the world, this area holds a high livestock population (Sinha et al. 1996; Sharma and Mehra 2009). Therefore, this desert has a history of intense human pressure in the form of overgrazing by livestock, and fuel wood collecting (Sharma and Mehra 2009). Soils are generally sandy and sandy-loam in texture and high in soluble salts (Gupta 1968). The low nutrients in the soil, its high sandy texture, low humidity, and intense zooanthropogenic pressure, inhibit large scale growth of terricolous lichens in the region. The terricolous lichen growth in this desert region is restricted to some

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high altitude, moist habitats such as Mount Abu (1,220 m). The dominant soil crust species in this region are those of bipartite cyanolichen (having cyanobacteria as the only photosynthetic partner) genus *Collema* (*C. ryssoleum*, *C. texanum*, and *C. thamnodes*) along with sporadic occurrence of *Phaeophyscia hispidula*.

The temperate-alpine habitats (1,500 to >3,500 m) in the Himalayas, with steep, inclined mountainous terrains, contain flat alpine grasslands locally known as *Bugyals*. These alpine grasslands harbour biological soil crusts, occasionally dominated by lichens (Rai et al. 2011, 2012). At lower altitude (1,800–2,000 m) lichen-dominated BSCs are rare but when they are present, they are not very diverse, whereas at mid- (≤3,400 m) to higher (>3,500 m) altitudes, lichen-dominated soil crusts are very diverse (Fig. 2.1). The temperate-alpine region of the Himalayas, are expected to be some of the most highly impacted lands by future climate changes as well as zooanthropogenic pressures (Rai et al. 2010, 2011, 2012). In *Bugyals*, sites with mosses tend to harbour a substantial population of lichens in the soil surface (Rai et al. 2011, 2012; Rai 2012). Lichens are abundant in the *Rhododendron*-rich middle-montane altitudes (3,000–3,400 m). The most abundant lichen in the grasslands is a tripartite (a fungus, having two photosynthetic partners—a green algae and a cyanobacteria) fruticose cyanolichen *Stereocaulon foliolosum*, which has low palatability (Ahti 1959, 1964; Ahti et al. 1973) and is a well established nitrogen fixer (Fig. 2.1). The reason *Stereocaulon* is so common may be due to its low palatability, and resistance to grazing pressure (Rai et al. 2012), and its ability to reproduce by fragmentation. The second most abundant lichen is *Cladonia* spp. (*C. coccifera*, *C. pyxidata*)-a compound lichen growth form (squamules as primary thallus bearing erect fruticose body as secondary thallus), which along with *Stereocaulon* spp. are more adapted to harsh alpine climate (Sheard 1968; Rai et al. 2011, 2012; Fig. 2.1). The habitats of Himalayas, usually inhabited by terricolous lichens, are regions with harsh climate, characterized by regular orographic precipitation, longer periods of snow fall, higher UV radiation, and freezing minimum (−30 ^{0}C) temperatures (Rai et al. 2011, 2012; Khare et al. 2010). Middle elevation (300–3,400 m) sites appear more favorable for soil lichen cover (Baniya et al. 2010), yet grazing pressure from livestock at middle altitudes and decrease in soil cover at higher elevations (>3,500 m) appears to limit their cover (Rai et al. 2011, 2012). However, from the foothills to the subalpine grasslands any lithic (rocky or shallow) soils have biological soil crusts. The species that occur in these sites are similar in composition to soil crusts around the world in similar sites. These lithic shallow soils are sometimes referred to as “bald” since they occur beyond the tree line and are dominated by grasses and herbaceous plants of *Asteraceae.*

2 Ecological Function of Soil Crusts and Terricolous Lichens

Biological soil crusts (BSCs) are a complex mosaic of cyanobacteria, green algae, lichens, mosses, microfungi, and other bacteria (Belnap et al. 2001). BSCs have a major influence on terrestrial ecosystems, including soil fertility and soil stability

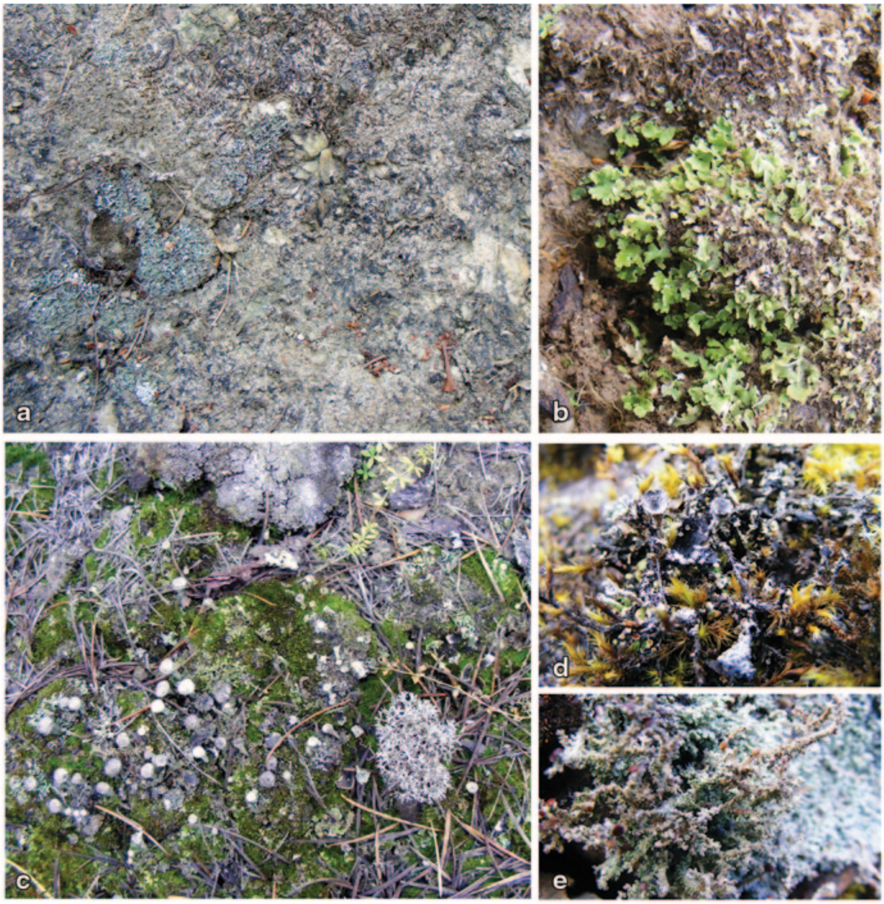

Fig. 2.1 **a, b** Lichen-dominated soil crust at lower altitude (1,800–2,000 m), with lower species diversity, dominated by *Cladonia coniocraea* (**b**). **c–e** Lichen-dominated soil crusts at mid- (≤3,400 m) to higher (>3,500 m) altitudes, with higher species diversity, **d** *Cladonia pyxidata*, **e** *Stereocaulon foliolosum*

(Belnap 2003). In the arid and semiarid habitats of the world, they may constitute as much as 70 % of living cover (Belnap 1994). In the western USA, BSCs are critical components of healthy ecosystems (Rosentreter and Belnap 2003). Biological soil crusts cover the arid and semiarid deserts around the world and have been studied in the western portions of North America the most (Rosentreter and Belnap 2003). The benefits of BSCs in the landscape cannot be understated. These benefits include: soil building, erosion reduction, greater water capture and retention by soils, lessening of severity of dust storms, control of invasive plants through inhibition of germination, soil temperature amelioration, help in soil microbial growth, moderation of fire events through reduction of fine fuels, and improving perennial plant growth (Belnap et al. 2001; Sofronov et al. 2004; Fig. 2.2). Lichen-dominated BSCs, as

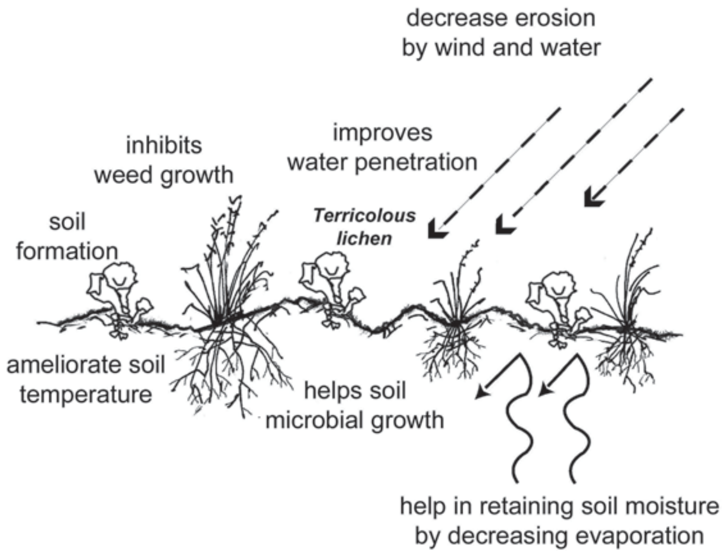

Fig. 2.2 Ecological benefits of lichen-dominated soil crusts in landscape ecology

a constituent of cryptogamic ground cover (CGC), along with cryptogamic plant cover (CPC) constitute a global continuum of cryptogamic cover, acting as major sink of atmospheric CO_2 and nitrogen accounting for about 7% of net primary production and about half of biologically fixed nitrogen in terrestrial biomes (Elbert et al. 2009, 2012).

Biological soil crust performs a number of roles in semiarid ecosystems. Structurally, soil crusts bind soil particles. Functionally, crusts alter the soil chemistry and increase the rates of decomposition. As such, crusts are considered to be ecosystem engineers (Bowker et al. 2004).

Studies on the functional role of soil crust lichens (terricolous lichens) in Himalayan habitats have shown that terricolous lichen plays a key role in the maintenance of a number of physicochemical properties of soil (i.e., aggregate stability, soil temperature, soil microbial respiration, and soil carbon–nitrogen content; Rai 2012). Besides influencing the soil properties, terricolous lichen distribution in Himalayas is also intricately correlated with the soil's physicochemical properties and competition with other ground vegetation (Rai 2012).

3 Ecological Distribution Patterns of Soil Lichens

Some of the same characteristics that influence the distribution of vascular plant taxa also influence BSCs and terricolous lichen development and distribution (Kaltenecker 1997). Relative cover of BSCs in various generalized vegetation types varies according to various topographical and hydrological properties of habitats. Lichen-dominated BSCs tend to lack vegetation types that occur on seasonally flooded soils as flooded soils create anaerobic conditions which are not tolerated by lichens. Saline soils also lack lichen cover, although mosses are sometimes present if the salt concentration is not too high. Dense vegetation types lack significant biological soil crust cover as the closed canopies of vascular vegetation and accumulating plant litter create too much shade on the soil surface. Other vegetation types support higher biological soil crust cover unless their soil surfaces are highly disturbed or the current vegetation is in an early or recovering successional stage.

Biological soil crust lichens sometime display specific site affinities on both fine and gross scales. Some terricolous lichens have a high affinity for calcareous substrates (e.g., *Aspicilia hispida, Buellia elegans, Caloplaca tominii, Collema tenax, Psora decipiens, Toninia sedifolia*; McCune and Rosentreter 2007). These calcicolous lichens indicate free calcium carbonate in the soil, and are good indicators of soil pH (McCune and Rosentreter 2007).

Terricolous lichens form natural replacement series along the same elevation and moisture gradients that influence vascular plants. For example, at low elevations in India, the cyanolichen genus *Collema* fixes nitrogen while at mid-elevations the genus *Stereocaulon* is the nitrogen fixer. Functionally, the gelatinous (blue-green algae containing) terricolous lichens are all nitrogen fixers, are more resistant and resilient to disturbance, and are common in arid calcareous sites or mesic noncalcareous sites (McCune and Rosentreter 2007). Therefore the terricolous lichen community composition will differ between the hot, dry deserts with higher calcareous soil and cooler, moist foothills-alpine habitats with mostly acidic soils (Rai et al. 2012; Table 2.1). Sites with frigid soil temperature regimes (the mean annual temperature is <8 C) lack significant cover of gelatinous lichens (Belnap et al. 2001). The genera *Peltigera* and *Massalongia* tend to be the common genera at these higher, more frigid elevations in North America while the genus *Stereocaulon* is common worldwide in frigid, high elevations (DeBolt and McCune 1993; Rai et al. 2012; Rai 2012). *Stereocaulon* is a common genus in open habitats at high elevations in India as well as Alaska, Canada and parts of South America (Rosentreter and Belnap 2003; Rai et al. 2011, 2012). Some species display a shift in substrate preference in different ecoregions. For example, in the Great Basin desert of North America, *Leptochidium albociliatum* occurs on mosses while in the moister Columbia Basin it is more common on bare mineral soil (Rosentreter 1986; Ponzetti et al. 1998).

4 Indicator Value of Terricolous Lichens

Terricolous lichens are good indicators of old-growth/late succession habitats (McCune and Rosentreter 2007). The dual gradient theory proposed by McCune (1993) for lichen species succession in forested habitats applies well to arid and semiarid regions where species respond to both time (age) and moisture in similar successional trajectories. Therefore, the length of time since the last major

Table 2.1 Comparison of the common lichens in the low elevation arid grassland/deserts versus the foothills-montane-alpine grasslands and steppes (Rai et al. 2012)

Arid low-elevation grasslands	Foothills-alpine grasslands and steppes
Collema tenax	*Cetrelia olivetorum*
Leptogium spp.	*Cladonia* spp.
Placidium spp.	*Everniastrum cirrhatum*
Endocarpon pusillium	*Lepraria* spp.
Lepraria spp.	*Stereocaulon foliolosum*
Heppia spp.	*Stereocaulon pomiferum*

disturbance of a site or an increase in effective soil moisture will both provide suitable ecological conditions to support specific lichen species. Late successional indicator species in arid steppe vegetation-type habitats include: *Acarospora schleicheri*, *Massalongia carnosa*, *Pannaria cyanolepra*, and *Trapeliopsis* species (Table 2.2). Some lichens only occur in stable, late successional communities because they only grow upon other lichen or moss species, e.g., *Acarospora schleicheri* spores germinate and grow upon the lichen, *Diploshistes muscorum*, which only grows upon the lichen genus *Cladonia*. Therefore, *Cladonia* can be considered a keystone species influencing the diversity of the site. *Massalongia carnosa* primarily grows on mosses and is not present until mosses become well distributed within a site (McCune and Rosentreter 2007). Another example from western North America is the rare lichen, *Texosporium sancti-jacobii* that is restricted to old-growth plant communities and occurs only on decaying organic matter (McCune and Rosentreter 1992). Other lichen species that commonly occur on decaying organic matter are: *Buellia papillata*, *B. punctata*, *Caloplaca* spp., *Lecanora* spp., *Megaspora verrucosa*, *Ochrolechia upsaliensis*, *Placynthiella* spp., and *Phaeophyscia decolor* (McCune and Rosentreter 2007).

A few common terricolous lichens that establish and grow quickly are early successional indicator species. The most common early successional lichen indicators are: *Collema tenax*, *Caloplaca tominii*, *Lepraria* spp., *Placidium* spp., and *Ochrolechia inaequatula*. Most of these species reproduce asexually, a life-history strategy which increases the probability of establishment (Rosentreter 1995). The presence, absence, and abundance of early- or late-successional species can provide information regarding the disturbance history of a site. Several early-successional species at a site indicate a recently disturbed site while several late-successional species at a site indicate less intensity or fewer disturbances in the recent history of the site. This information, combined with data on vascular plant community composition, can assist the land manager in understanding the disturbance history, potential productivity, and integrity of a site. Due to this ecological history at a site, the phase, “Lichens don’t lie” is often used to demonstrate that the lack of late-successional lichens indicating that domestic grazing animals have disturbed the area.

The potential soil crusts and lichen cover for a given site are influenced by factors such as, associated vegetation, humidity/precipitation, soil texture, ecological successional stage, fire incidence frequency, and grazing pressure (Table 2.3). Soil

Table 2.2 Early and late successional terricolous lichens in arid habitats

Early successional soil lichens	Late successional soil lichens
Collema tenax	*Acarospora schleicheri*
Cladonia spp.	*Massalongia carnosa*
Placidium spp.	*Pannaria* spp.
Caloplaca toninii	*Trapeliopsis* spp.
Ochrolecia inaequatula	*Cetrelia* spp.
Lepraria spp.	*Cetraria* spp.

texture and vegetation of the site are critical factors (Kaltenecker et al. 1999). The factors listed are closely related and are components of the ecological site; however ,variation in any one factor can influence biological soil crusts crust cover and its relative importance to the ecological stability of the site (Hilty et al. 2004). In general, ecological sites dominated by bunch-grass grasslands will consistently have a well-developed "high" biological soil crust cover (Rosentreter and Belnap 2003). Soil texture of a site influences the stability of soil matrix, e.g., arid grasslands communities occurring on calcareous, gravelly loams and silt loams (such as alluvial deposits) have well developed lichen crusts that occupy fine-textured, mineral soil within a stabilized gravel matrix and are protected from livestock tramping (Table 2.3). The livestock impact on soil crust lichens is determined by the season of use and utilization intensity. Vegetation utilization is representative of animal stocking rates (number of sheep etc.) or length of grazing period. Severe to high utilization is indicative of localized concentration of animals and heavy trampling. Again, trampling impacts will be more severe if the soils are dry. Although the moisture required by soil crust community is lower than that needed by vascular plants, it is an important influencing factor in growth and development of diverse terricolous lichen community. Soil crusts are fragile when dry (dormant), but quite pliable when moist. Least impact occurs when the crust is moist or frozen but not saturated (Belnap et al. 2001).

5 Ecological Patterns of Terricolous Lichens in India

Terricolous lichens in India, more or less share the same distribution ecology patterns, which globally influence soil crusts. Soil crust formation in India is greatly influenced by grazing-induced disturbances (Rai et al. 2012). Terricolous lichens in the foothills, and montane grasslands are better developed than desert regions, and more diverse due to the limited season that livestock can access and trample these habitats (Rai et al. 2012; Sinha et al. 1996). Livestock-induced trampling has been a dominant factor influencing the distribution of soil lichens in India (Rai et al. 2011, 2012; Rai 2012). The sandy textured soils of deserts are unstable when dry and have

Table 2.3 Site potential for the occurrence of biological soil crusts, evaluation sheet

Potential for biological soil crusts crust development based on physical and biological factors (based on site potential relative to herbaceous cover)				
Crust cover	High >25 % cover	Moderate >25–15 %	Low >15–3 %	Very low >3 %
Dominant vegetation type	Arid grasslands	Foothills, grasslands	Foothills and Montane steppe	Open woodland
Herbaceous plant density	Low	Low-moderate	Moderate-high	High
Dominant herbaceous life form	Bunchgrass	Bunchgrass	Bunchgrass/rhizomatous plants	Rhizomatous plants
Annual precipitation	<300 mm	300–360 mm	>360–410 mm	>410 mm
Soil surface texture (* most critical factor)	Silts-fine silt loams clays (excluding shrink/swell clays)	Loamy	Sandy, shrink-swell clays	Coarse sand gravel or broken rock (>80 % rock fragment) desert pavement
Surface rock Cover	>1 % *s*table, *e*mbedded rocks	<1 % *s*table, embedded rocks	Mostly unstable rocks, not embedded	Only unstable rocks
Historical fire return interval	>50 years (this would include most bunchgrass habitats.	25–50 years	10–25 years	<20 years
Current ecological condition	Mid- to late seral or potential natural community	Early- to mid-seral	Disturbed to early-seral	Disturbed or with weedy plant cover
Likelihood for a change in management to negatively impact the biological soil crusts				
	High	Medium	Low	Very Low
Current livestock season of use	Warm dry periods	Cool dry periods	Cool moist periods	Cold moist periods
Vegetation utilization by grazing	Severe to high >50 %	Moderate <50 %	Light <35 %	Slight <25 %

Impacts of livestock grazing on biological soil crusts crust are judged to be (1) significant, (2) present but not significant or (3) not present. This judgment is based upon site specific data or completion of the above table. This table is not a substitute for field knowledge or monitoring data. The table may be used to describe the analysis of the impacts of livestock grazing on biological soil crusts cover. This table can be used in most arid habitats. Most data collected relative to this table were developed in the Great Basin desert of the western USA been severely impacted by livestock trampling whereas, fine textured soil in the montane grasslands and steppe are more tolerant.

Though the major distribution of terricolous lichens and soil crust in India is restricted to foothills and the Himalayan montane grasslands (Rai et al. 2012, 2013; Rai 2012), the western dryer desert region holds a restricted distribution of terricolous lichen genera *Collema* (*C. ryssoleum*, *C. texanum*, and *C. thamnodes*) and *Phaeophyscia hispidula*. Both the lichen genera are calcophilic (most of the soils of western India have higher calcium carbonate content) and are found in Mount Abu region (Awasthi 2007), which is relatively more moist and free from livestock grazing. The Himalayan terricolous lichen community is dominated by species of *Stereocaulon* and *Cladonia* followed by Peltigera *praetextata, P. rufescence,* and *Xanthoparmelia terricola* (Rai et al. 2012; Rai 2012). Himalayan soil crust lichens are better adapted to acidic soils.

6 Conclusion

Although the distribution of soil crust lichens in India broadly follows the global ecological patterns, showing striking taxonomic and ecological similarity with soil crust communities worldwide, their growth and development is constrained by constantly increasing grazing pressures. Furthermore, the rapidly changing land-use patterns in lichen-rich Himalayan habitats, is also proving detrimental to the survival of these soil crust species.

References

Ahti T (1959) Studies on the caribou lichen stands of Newfoundland. Ann Bot Soc Zool Bot Fenn 'Vanamo' 30:1–43

Ahti T (1964) Macrolichens and their zonal distribution in boreal and arctic Ontario, Canada. Ann Bot Fenn l:l–35

Ahti T, Scotter GW, Vänskä H (1973) Lichens of the reindeer Preserve, Northwest Territories, Canada. Bryologist 76:48–76

Awasthi DD (2007) A compendium of the macrolichens from India, Nepal and Sri Lanka. Bishen Singh Mahendra Pal Singh, Dehra Dun, pp 580

Baniya CB, Solhøy T, Gauslaa Y, Palmer MW (2010) The elevation gradient of lichen species richness in Nepal. Lichenologist 42:83–96

Belnap J (1994) Cryptobiotic soil crusts: basis for arid land restoration (Utah). Restor Manage Notes 12:85–86

Belnap J (2003) Biological soil crusts and wind erosion. In: Belnap J, Lange OL (eds) Biological soil crusts: structure, function, and management, ecological studies. Series 150. Berlin, Springer, pp 339–347

Belnap J, Kaltenecker JH, Rosentreter R, Williams J, Leonard S, Eldridge D (2001) Biological soil crusts: ecology and management. USDI Bureau of Land Management National Science and Technology Center, Tech. Ref. 1730–2

Bowke MA, Belnap J, Rosentreter R, Graham B (2004) Wildfire-resistant biological soil crusts and fire-induced loss of stability in Palouse prairies, USA. App Soil Ecol 26:41–52

DeBolt A, McCune B (1993) Lichens of Glacier National Park, Montana. Bryologist 96:192–204

Elbert W, Weber B, Büdel B, Andreae MO, Pöschl U (2009) Microbiotic crusts on soil, rock and plants: neglected major players in the global cycles of carbon and nitrogen. Biogeosciences Discuss 6:6983–7015

Elbert W, Weber B, Burrows S, Steinkamp J, Büdel B, Andreae MO, Pöschl U (2012) Contribution of cryptogamic covers to the global cycles of carbon and nitrogen. Nat Geosci 5:459–462

Gupta RS (1968) Investigation on the desert soils of Rajasthan fertility and mineralo-gical studies. J Indian Soc Soil Sci 6:115–121

Hilty JH, Eldridge DJ, Rosentreter R, Wicklow-Howard MC, Pellant M (2004) Recovery of biological soil crusts following wildfire on the Snake River Plain, Idaho, U.S.A. J Range Manag 57:89–96

Kaltenecker J (1997) The recovery of microbiotic crusts following post-fire rehabilitation on rangelands of the western snake river plain. M.S. Thesis, Boise State University, Boise, ID, U.S.A.

Kaltenecker JK, Wicklow-Howard MC, Rosentreter R (1999) Biological soil crusts in three sagebrush communities recovering from a century of livestock trampling. In: McArthur ED, Ostler KW, Wambolt CL (comps.) Proceedings; 1998 August 12–14; Ephraim, UT. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 222–226. Shrubland ecotones (1999)

Khare R, Rai H, Upreti DK, Gupta RK (2010) Soil Lichens as indicator of trampling in high altitude grassland of Garhwal, Western Himalaya, India. Fourth National Conference on Plants & Environmental Pollution, 8–11 Dec. 2010, pp 135–136

McCune B (1993) Gradients in epiphyte biomass in three *Pseudotsuga-Tsuga* forests of different ages in western Oregon and Washington. Bryologist 96:405–411

McCune B, Rosentreter R (1992) *Texosporium sancti-jacobi*, a rare western North American lichen. Bryologist 95:329–333

McCune B, Rosentreter R (2007) Biotic soil crust lichens of the Columbia Basin. Monogr N Am Lichenol 1:1–105

Ponzetti J, Youtie B, Salzer D, Kimes T (1998) The effects of fire and herbicide on microbiotic crust dynamics in high desert ecosystems. Corvallis: U.S. 107 Department of Agriculture, Forest and Rangeland Ecosystem Science Center, Oregon State University

Rai H (2012) Studies on diversity of terricolous lichens of Garhwal Himalaya with special reference to their role in soil stability. PhD Thesis. H.N.B Garhwal University. Srinagar (Garhwal), Uttarakhand, India

Rai H, Khare R, Gupta RK, Upreti DK (2011) Terricolous lichens as indicator of anthropogenic disturbances in a high altitude grassland in Garhwal (Western Himalaya), India. Bot Orientalis 8:16–23

Rai H, Nag P, Upreti DK, Gupta RK (2010) Climate warming studies in alpine habitats of Indian Himalaya, using lichen based passive temperature-enhancing system. Nat Sci 8:104–106

Rai H, Upreti DK, Gupta RK (2012) Diversity and distribution of terricolous lichens as indicator of habitat heterogeneity and grazing induced trampling in a temperate-alpine shrub and meadow. Biodivers Conserv 21:97–113

Rai H, Khare R, Nayaka S, Upreti DK (2013) The influence of water variables on the distribution of terricolous lichens in Garhwal Himalayas. In: Kumar P, Singh P, Srivastava RJ (eds) Souvenir, water & biodiversity, vol 7, pp 75–83. International day for biological diversity, Uttar Pradesh State Biodiversity Board, 22 May 2013

Rosentreter R (1986) Compositional patterns within a rabbitbrush (*Chrysothamnus*) community of the Idaho Snake River Plain. in McArthur EE Welch BL, comps (eds) Proceedings of the Symposium: Biology of *Artemisia* and *Chrysothamnus*. Gen. Tech. Report INT-200, Ogden, UT

Rosentreter R (1995) Lichen diversity in managed forests of the Pacific Northwest, USA. 103–124 pp. In: Conservation of Lichenized Fungi. Scheidegger C, Wolseley PA, Thor G (eds) 1995. Mittenelumgen der Eidgenossischen Forschungsanstalt fur Wald. Schenee und Landschaft 70, 1:1–173. Birmensdorf, Switzerland

Rosentreter R, Belnap J (2003) Biological soil crusts of North America. In Biological Soil Crusts: Structure, Function, and Management, Ecological Studies Series 150. In: Belnap J, Lange OL (eds) Berlin, Springer, pp 31–50
Scheidegger C, Clerc P (2002) Erdbewohnende Flechten der Schweiz. In Rote Liste der gefährdeten Arten der Schweiz: Baum- und erdbewohnende Flechten, pp 75–108
Sharma KK, Mehra SP (2009) The Thar of Rajasthan (India): ecology and conservation of a desert ecosystem. In: Sivaperuman C et al. (eds) Faunal ecology and conservation of the Great Indian Desert. Springer, Berlin
Sheard JW (1968) Vegetation pattern on a moss-lichen heath associated with primary topographic features on Jan Mayen. Bryologist 71:21–29
Sinha KR, Bhatia S, Vishnoi R (1996) Desertification control and rangeland management in the Thar desert of India. RALA Report No. 200, 115–123
Sofronov MA, Volokitina AV, Kajimoto T, Uemura S (2004) The ecological role of moss-lichen cover and thermal amelioration of larch forest ecosystems in the northern part of Siberia. Eurasian J For Res 7:11–19