Himanshu Rai · Dalip K. Upreti *Editors*

Terricolous Lichens in India

Volume 2: Morphotaxonomic Studies

Springer

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Cladonia fimbriata taken at 3,170 m, at Gangotri town in Uttarkashi district of Uttarakhand, India on 28 Oct 2010. The sample is preserved in the CSIR-NBRI herbarium with collection no.: 10-0014513 (LWG) by Himanshu Rai and Pramod Nag. Photographed using Fujifilm FinePix S5800 S800 camera.

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Preface

Lichenological investigations now recognize about 2,305 species of lichens in India. The consistent efforts of some dedicated lichenological centres in India, has contributed a lot in discovering new species and new records from the vast and some of the most heterogeneous habitats in Southeast Asia. Although in last 50 years the focus of lichenological investigations in India has been mainly taxonomic, lichen functional groups, such as terricolous lichens, are only mentioned in usual taxonomic enumerations along with other lichen groups. There is no comprehensive monograph available on terricolous lichens for Indian habitats. With increase in the understanding on soil crust lichens, their functional role in maintenance of physical stability, hydrology and nutrient pool of soil crust is well recognized worldwide (Elbert et al. 2012). The investigations on Indian terricolous lichens were initiated at Lichenology Laboratory of CSIR-National Botanical Research Institute (NBRI) as an assessment of their diversity in Western Himalaya and their role in soil stabilization in alpine habitats (Rai 2012). The study revealed a substantial diversity of terricolous lichens and found that soil lichens play a very crucial role in stabilization of soil crust, soil respiration, amelioration of soil temperature and growth of soil microflora. In the course of study, need of a comprehensive taxonomic account of terricolous lichens was realized leading to conceptualization of this volume, which deals with taxonomy of terricolous lichens of India.

With a background of different patterns of diversity and distribution ecology of soil lichens in volume I, this volume II of *Terricolous Lichens in India* intends to describe the taxonomic account of soil lichens of India. The volume is the outcome of extensive field collections and investigation of about 4,500 specimens preserved in various national and international herbaria. The volume is divided into two chapters. The first chapter describes the basics of soil lichen curation from Indian habitats, various morpho-anatomical and chemical techniques for taxonomic identification and introduces the morpho-anatomical features of terricolous lichens. The second chapter deals with the taxonomy of 312 terricolous lichen species, with their detailed identification keys and taxonomic description. The taxonomic diagnostics is complemented with photographs of lichens for visual identification, along with their distribution maps. The book should be of interest to the specialists and also intends to generate interest among ecologists, biologists, naturalists, teachers,

students, protected area managers, policy makers and conservation agencies. We hope that this book will widen the overall understanding of Indian lichens and specifically the terricolous lichens, both for native as well as international workers and would serve as foundation of many more taxonomic as well as applied researches in Indian lichens.

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Chapter 1
Terricolous Lichens of India: An Introduction to Field Collection and Taxonomic Investigations

Himanshu Rai, Roshni Khare, Dalip Kumar Upreti and Sanjeeva Nayaka

1 Introduction

Lichenological investigations in India, although still constrained by unbalanced collections, where some regions are exhaustibly investigated (e.g. Western Himalayas and Palni Hills) and others are still unexplored (e.g. eastern India), have recorded about 2,303 species of lichens (Upreti 1998; Singh and Sinha 2010). In the last 50 years, there has been tremendous advancement in elucidation of lichens from India (Singh 2011); however, there are few publications dealing with specific group (i.e. family/functional group) of Indian lichens (Divakar and Upreti 2005; Singh 2011).

Although soil-inhabiting terricolous lichens have been mentioned in various enumerations and taxonomical records (Chap. 1, Vol. 1), they have not been explored as a functional group (Rai et al. 2012). Lichen biogeographical diversity, when analyzed along species composition similarity, can give an overview of diversity of lichens within a particular geographical setting (Feuerer and Hawksworth 2007). On the basis of updated data after Singh and Sinha 2010 (resulting in 2,368 species) and taking into consideration ten dominant families and genera along with endemism, lichen diversity in India can be divided into eight lichenogeographical regions (Fig. 1.1) (Singh and Sinha 1997; Negi 2003). The distribution of lichens in different lichenogeographical regions shows dominant distribution of terricolous lichen families (e.g. *Cladoniaceae*, *Collemataceae*) and genera (e.g. *Cladonia*, *Collema*, *Leptogium*) in Himalayan habitats along with their fair presence in other regions (Fig. 1.1).

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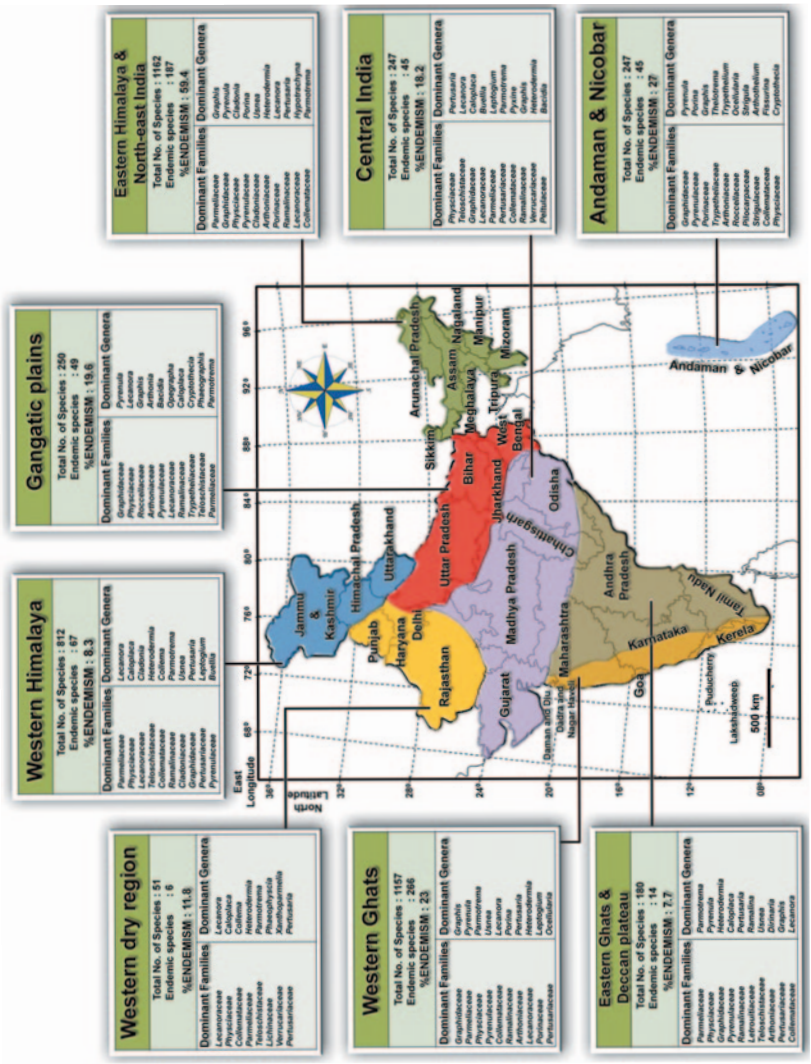

Fig. 1.1 Map of India showing its political boundaries, constituent states/union territories and eight lichenogeographical regions

2 Terricolous Lichens: Habitat Differentiation

Although soil-crust lichens in India, along with other cryptogams (blue-green algae and mosses), form biological soil crusts in Himalayan habitats (Chap. 2, Vol. 1), their major inhabitance is on soil accumulated over rocks (rupicolous–terricolous habitat) (Chap. 5, Vol. 1). Terricolous lichens, in strict sense, are lichens that inhabit ground directly in soil, sand, peat or humus (Scheidegger and Clerc 2002). Besides this strict habitat delimitation, based on various microhabitat differentiations, following principal types of soil lichens are recognized in India (Scheidegger and Clerc 2002).

1. Species that grow on the ground directly in soil, sand, peat or humus are regarded as *soil-inhabiting (terricolous) lichens* in the narrow sense (Fig. 1.2a).
2. Species that grow on the ground in mosses, which in turn are rooted in earth or sand, are considered as *muscicolous–terricolous lichens* (Fig. 1.2b).
3. Species that grow on accumulated soil in rock crevices or on the rough surfaces of rocks are considered as *terricolous–rupicolous lichens* (Fig. 1.2c, d).
4. Species that thrive on mosses, which in turn are rooted directly on rocks (having some accumulated soil or organic debris), are considered as *muscicolous–rupicolous lichens* (Fig. 1.2e).
5. Species that grow directly on the ground on plant remains are regarded as *detriticolous–terricolous lichens* (Fig. 1.2f).

3 Collection and Curation of Terricolous Lichens in India

The taxonomic studies of terricolous lichens are delimited by poor curation and the resulting lack of good specimens, as the soil substratum becomes very fragile, during specimen removal in the field and during transit to the laboratory. Collection of terricolous lichens requires special attention right from the field. Owing to the fragility and crumbling nature of soil substratum of terricolous lichens, moistening of lichens with a fine sprayer (mister) ensures easy removal of lichens with 1–5 cm of crust (Rosentreter 1988; Awasthi 2000). As the dominant microhabitat of soil lichens in India is soil over rocks or rock crevices, pointing trowel (mason's trowel) is very useful in removing terricolous lichens from the rocky relevés (Fig. 1.3a, b). Soil crusts with soil samples have to be wrapped in several layers of tissue paper (3 ply) and then placed in firm plastic containers for transit to laboratory to reduce the risk of further crumbling of soil crust and specimen destruction (Fig. 1.3c, d) (Rosentreter 1988). The transportation of specimens to laboratory must be done with extra care to avoid fragmentation of samples.

After air drying the specimens, maximum amount of soil is removed from the samples wherever possible, or a fair amount of soil crust (1–2 cm) is retained in order to maintain the integrity of lichen thalli. Terricolous lichen samples with soil crust are dipped into water-based glue, which gradually seeps into the soil from

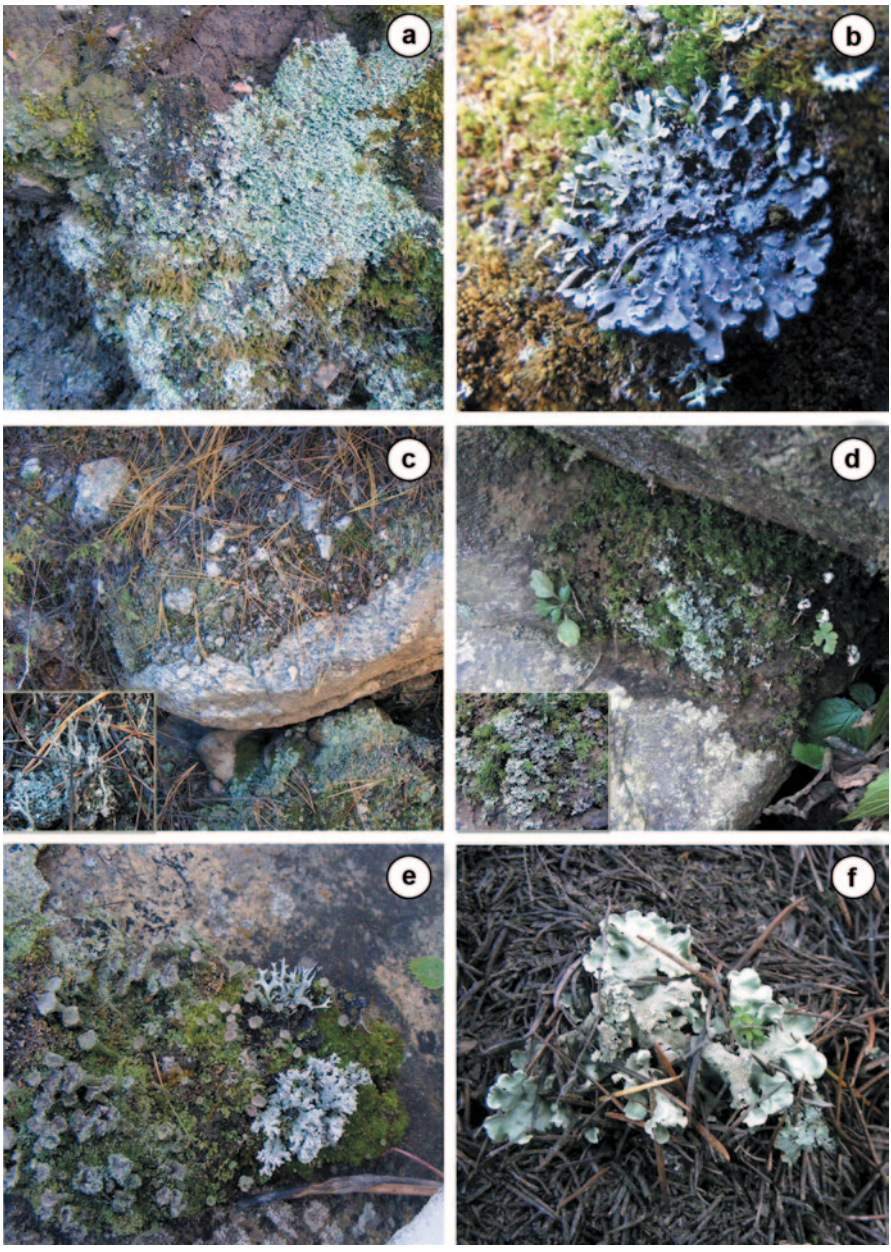

Fig. 1.2 Microhabitat differentiation in terricolous lichens of India. **a** Terricolous (soil-inhabiting) lichens. **b** Muscicolous–terricolous (on ground on moss) lichens. **c**, **d** Terricolous–rupicolous (on accumulated soil on rock surface or rock crevices) lichens, inset (magnified lichen thallus). **e** Muscicolous–rupicolous (on mosses, which are rooted on rocks, having some accumulated soil or organic debris) lichens. **f** Detriticolous–terricolous (grow directly on the ground on plant remains) lichens (after Scheidegger and Clerc 2002)

Fig. 1.3 Collection and curation of terricolous lichens from field. **a**, **b** Collection of terricolous lichens along with their substratum, using pointing trowel (mason's trowel). **c** Placing terricolous lichens in firm plastic containers for transportation to laboratory. **d** Soil lumps with terricolous lichens in laboratory (before mounting). **e** Terricolous lichens mounted (glued) to archival quality cardboard (samples having maximum of soil removed). **f** Terricolous lichens mounted on cards with styrofoam packing material at the perimeter (samples with their soil substratum intact)

below, and dried to prevent the crumbling of the soil and retain the lichen in its position (Rosentreter 1988; Awasthi 2000). The prepared terricolous lichen samples are either mounted on cards directly (sample having maximum soil removed) (Fig. 1.3e) or on cards with glued strips of styrofoam (thicker than the mounted specimen so that the surrounding packet rests on them rather than on specimen) packing material around the perimeter to help eliminate breakage of the crusted samples when filed or stacked (Fig. 1.3f) (Rosentreter 1988). Additional protection is achieved by covering the specimen with a piece of tissue paper.

4 Taxonomic Identification of Terricolous Lichen Specimens

Taxonomic investigation of terricolous lichen samples is done by usual microscopic morphoanatomical observations and lichenological chemical tests (i.e. spot tests, thin-layer chromatography (TLC), microcrystallization and ultraviolet (UV) reactions).

4.1 Morphoanatomical Examination

External morphology is examined by stereomicroscopes, at magnifications enough for proper identification of characteristic morphological features. Thin hand-cut sections of apothecia and thalli are mounted in plain water, lactophenol cotton blue, 5 % KOH and iodine solution and observed under a compound microscope.

The external morphology is generally examined in dry conditions, but dark brown to bluish specimens of *Leptogium* and *Collema* are studied in wet conditions. The colours of medulla, epithecium, hypothecium and ascus are recorded. The asci and ascospores are taken from the sections, and their shapes and sizes are recorded when mounted in water.

4.2 Chemical Examinations

Chemistry of the specimens includes colour tests, TLC and microcrystallization.

4.2.1 Colour Tests

Specific chemical reagents having tendency to give diagnostic colours when applied to lichen thallus and medulla, resulting in change in colour, are used for colour tests. In taxonomic descriptions, the results of the colour tests are reported as positive change, denoted by a positive symbol (+), or no change, denoted by a negative symbol (−). The chemical reagents used are as follows (Orange et al. 2001):

K test Aqueous solution of potassium hydroxide (10 %, 10 g KOH pellets + 100 ml distilled water) is applied to the cortex, the medulla and a part of apothecia. This aqueous solution of KOH is used as a clearing agent for sections of fruiting bodies and thalli, as it often dissolves the crystalline lichen substances and removes some mucilage that may obscure the details of the sections.

Pd test A stable solution of *para*-phenylenediamine, termed Steiner's Pd, is prepared by dissolving 1.0 g of *para*-phenylenediamine and 10 g of sodium sulphite in 100 ml of distilled water with 0.5 ml of a liquid detergent. This reagent remains usable for about a month.

C test Freshly prepared aqueous solution of calcium hypochlorite or bleaching powder or modern commercial bleaching fluid containing active chlorine is prepared by dissolving calcium hypochlorite in distilled water.

KC test At a particular spot of thallus, K is applied first and immediately followed by C.

Iodine reaction Iodine forms coloured complexes with some of the classes of polysaccharides (rarely with other lichen substances), which are formed in hyphal walls and in extracellular gels; these reactions are valuable at taxonomic levels. Lugol's solution (0.5 g of iodine is dissolved in 100 ml of water containing 0.5 g of potassium iodide) is used in routine I reactions (Hawksworth et al. 1995). The reagent is usable for several days and should be renewed when colour fades.

Other colour tests A dilute aqueous solution of nitric acid and an aqueous solution of ferric chloride are sometime used for the identification of *Melanelia* species. Spot tests can be done on any part of the thallus, but younger parts give better results. Colour test is done on a small fragment of the desired lichen thallus part or thallus or ascocarp. A definite colour develops, showing the presence of any lichenic acid.

4.2.2 Microcrystallization

Introduced by Asahina (1936 and1938), the microcrystallization method relies on the characteristic crystal forms assumed by lichen substances when recrystallized in a suitable solvent. Although largely superseded by the more sensitive and reliable method of TLC, this technique is still useful for a small number of lichen compounds. The method is of most use when a small number of taxa of known chemistry are to be separated.

A small fragment of lichen to be investigated is placed on the middle part of a microscopic glass slide and one or two drops of acetone are dripped on the fragment by means of a dropper. Following the evaporation of acetone, lichen substances, if present, get extracted on the slide as residue in the form of a ring around the fragment. The thallus fragment is then removed. A micro cover glass is placed over the residue and a drop of one of the crystallizing fluids (detailed later) is placed at the edge of the cover glass. The fluid gradually seeps in. The slide is then heated gently

over a sprit lamp. The residue dissolves in the fluid and lichen substances gradually crystallize into their characteristic shapes on cooling. These crystals are observed under low-power microscope and identified by comparison with the photographs or line diagrams published by Huneck and Yoshimura (1996), Hale (1974) and Orange et al. (2001). Identification of depsides, depsidones and dibenzofurans is usually confirmed by this method. The crystallizing fluids used are as follows:

a. G.E.—glycerol:acetic acid, 1:3
b. G.A.W.—glycerol:ethanol:water, 1:1:1
c. An—aniline:glycerol:ethanol, 1:2:2
d. *o*T—*o*-toluidine:glycerol:ethanol, 1:2:2
e. Py—pyridine:glycerol:water, 1:1:3
f. Q—quinoline:ethanol:glycerol, 1:2:2
g. KK- potassium hydroxide: potassium carbonate: water, 1:4:20

4.2.3 Thin-Layer Chromatography (TLC)

We performed TLC mainly in solvent system A containing toluene, 1, 4-dioxane,and acetic acid in the ratio 180:45:5 (Culberson and Ammann 1979). The chemical substances are extracted in acetone and loaded on TLC plates of size 20 × 20 cm, made of aluminium and coated with a layer of silica (MERCK^{TM} TLC Silica gel 60 F_{254}). These plates contain an indicator which fluoresces under short UV wavelength. The samples are loaded on loading front, drawn with a soft pencil, 20 mm from the base of the plate. Samples are loaded at 10 mm intervals on the loading line. Solvent system is run up to 130 mm from the base, marked as finishing line of solvent front. *Parmelinella wallichiana* (Taylor) Elix & Hale, having salazinic acid (R_f class 2) and atranorin (R_f class 7), is used as reference/control (Awasthi 2000). After running in the solvent system, the TLC plates are sprayed with distilled water for the presence of fatty acids, and are examined under UV light of short (254 nm) or long (366 nm) wavelength. Any fluorescence observed is marked or noted at the place of occurrence. Later, the plates are sprayed with freshly prepared 10% H_2SO_4 solution and heated in hot air oven at 110 °C until (5–10 min) the colour spots are developed because of charring. The plate is taken out and allowed to cool. The distance travelled in a particular solvent is characteristic for each substance, which can be expressed as the R_f value (retention value). The colours of the spots and the position for each extract are noted; the plate is again observed under UV light and finally the R_f value is calculated. Absolute values may vary considerably with a slight variation in experimental setup. One common method to overcome this variation is to divide the TLC plates into classes of R_f values, i.e. R_f classes.

$$R_f = \frac{\text{distance travelled by lichen substance (indicated by spot)}}{\text{distance travelled by solvent (solven front)}}$$

Control specimens which contain substances with well-known R_f values like norstictic acid (R_f class 4) and atranorin (R_f class 7) are used to “calibrate” the plates.

Another way to overcome experimental variation is the calculation of relative rather than absolute R_f values.

Identification of lichen substances is made on the basis of the comparison of position and colour of the spots by charts and data published in relevant references (Elix and Ernst-Russel 1993; Orange et al. 2001). The guidelines of Orange et al. (2001) were followed for TLC. Lichen substance identification in TLC was further confirmed using the software WINTABOLITES, which has library records of 711 lichen substances from the study of Orange et al. 2001 (Mietzsch et al. 1994).

UV test A number of secondary metabolites in lichens exhibit a characteristic fluorescence under UV light. The response of presence and absence of these metabolites in the form of fluorescence against UV light plays a vital role in the lichen identification.

Morphoanatomical investigation along with chemical studies forms an essential component of taxonomic determination of lichens species. Following is a brief description of various morphological features (growth forms, vegetative propagules, and other surface structures), anatomical features (thallus anatomy), fruiting bodies (apothecia) and spore types, which are essential for proper delimitation of Indian terricolous lichen species.

5 Terricolous Lichen Morphology

Unlike other lichens (epiphytic or rock dwelling), terricolous lichens are often covered with soil debris; therefore, proper removal of soil and associated debris is essential for morphological analysis. Blue-green algae containing cyanolichens need moistening of thallus for the proper morphological examination.

5.1 Growth Forms

The morphology of terricolous lichens like other lichens groups can be categorized into three main growth forms (Nash III et al. 2002) (Fig. 1.4):

1. ***Crustose*** (crust-like) lichens consist of an adherent crust within or on the substrate and lack cortex and rhizines at the lower surface. Among crustose lichens, many growth forms are distinguished:
   Areolate thalli are characterized by small broken independent crustose areoles, e.g. *Acarospora* (Fig. 1.4a).
   Leprose lichens represent the least organized crustose form in which thallus is in the form of a powder or finely granular mass of algal cells and fungal hyphae and are never delimited by cortical layers, e.g. *Lepraria* spp. (Fig. 1.4b).
   Bullate thalli are composed of inflated, swollen areoles, e.g. *Toninia* spp..

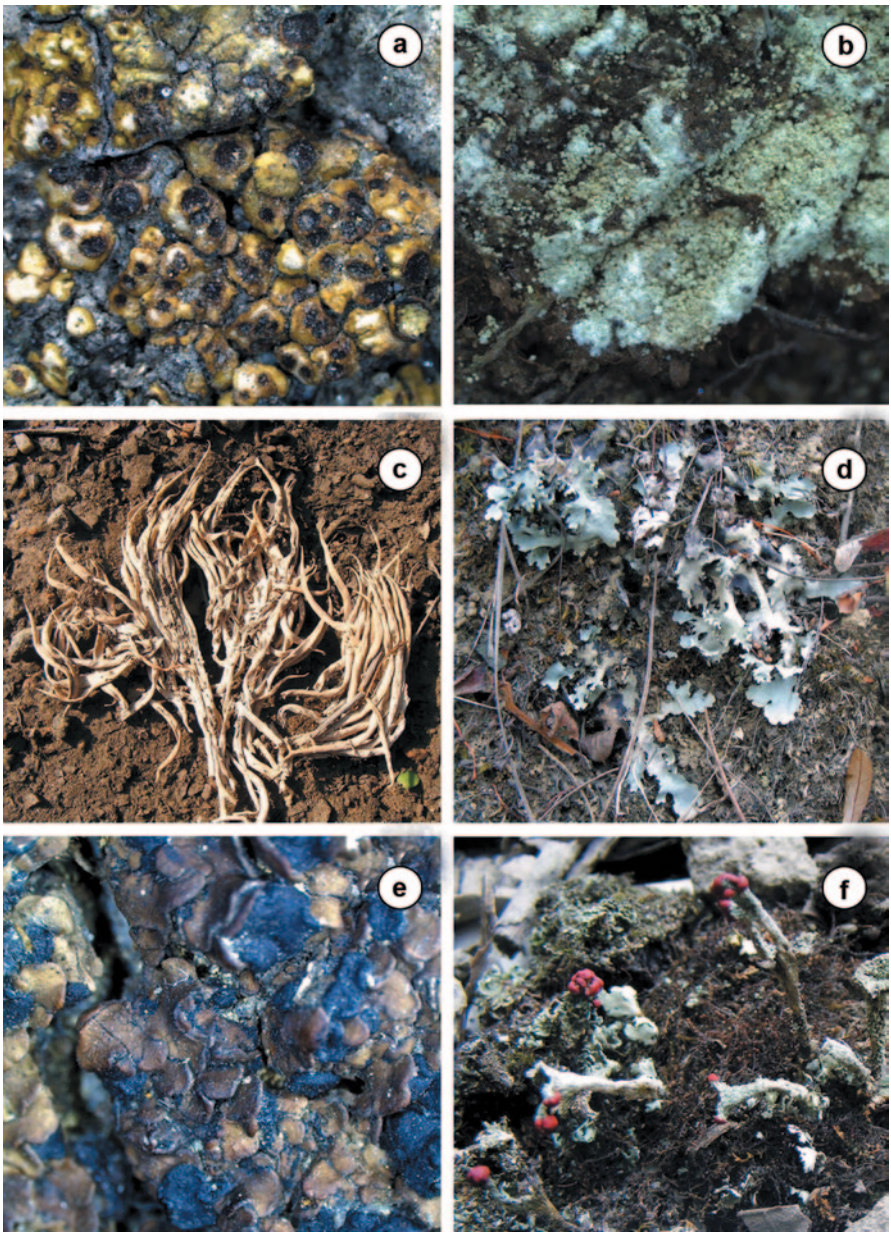

Fig. 1.4 Growth form diversity in terricolous lichens. **a** Crustose, **b** Leprose, **c** Fruticose, **d** Foliose, **e** Squamulose, **f** Compound

Squamules have irregularly scattered areoles, which become minutely lobed and scale–like, e.g. *Endocarpon* spp., *Heppia* spp., *Catapyrenium* spp., *Placidium* spp. (Fig. 1.4e).

2. ***Foliose*** (leaf-like) are usually dorsiventrally differentiated with a distinct upper and lower surface and are commonly attached to substratum by structures like rhizines or umbilicus, e.g. *Peltigera*, *Hypogymnia*, *Sticta*, *Umbilicaria*, *Parmotrema*, *Dermatocarpon* (Fig. 1.4d)
3. ***Fruticose*** (shrub or beard-like) are bushy shrub-like and are either erect or pendulous, e.g. *Thamnolia* spp., *Ramalina* spp. (Fig. 1.4c).

Besides these forms, many intermediate forms are observed, e.g. subfruticose and subfoliose.

4. ***Dimorphic/compound***: There are two terricolous lichens, *Cladonia* and *Stereocaulon*, in which more than one growth forms combine to form thallus, called as *cladoniiform* (Fig. 1.4f). These lichens have a basal granular or squamulose *primary thallus*, which extends horizontally on substrate and gives rise to erect stalks or branches referred to as *secondary thallus*. In *Cladonia*, these stalks are called *podetia*, which are hollow and are modifications/extensions of reproductive structures like apothecia or pycnidia. In *Stereocaulon*, the upright stack known as *pseudopodetia* are thalline in origin and solid throughout. Conventionally, termed as *dimorphic* thalli (Ahti 2000), these thalli are also reported as *compound*, as the so-called secondary thallus is just a modification of fruiting structures (Rai et al. 2012).

5.2 Vegetative Propagules

Vegetative propagules in terricolous lichens, like other lichens, usually integrate both mycobiont and photobiont cells and are among the most common mode of asexual reproduction (Nash III et al. 2002). Some of the most encountered vegetative propagules in terricolous lichens are soredia, isidia and schizidia.

Soredia are dispersal units of photobiont cells aggregated with loosely interwoven hyphae. Their morphology varies from fine (*farinose*) to coarse, grain-like (*granular*) or occasionally aggregate in large clusters (*consoredia*). Soredia are produced in well-defined structures, called *soralia*, which may be laminal or marginal. The region of thallus where soredia are formed, cortex breaks and the powdery mass of soredia comes out, giving the thallus surface a granular appearance.

Isidia are minute out growths with similar organization as the lichen thallus. Covered by cortical layers, isidia often has an internal differentiated photobiont layer. Isidial morphology varies, which ranges from simple to branched, coralloid, globose, and flattened. Isidia function as vegetative dispersal units, as they are loosely attached to the thallus surface. They are either distributed all over the thallus or to margins or ridges. Flattened isidia develop into small scale-like lobes, which are often referred to as *phyllidia*, observed in *Nephroma*, *Peltigera* and *Sticta*. Phyllidia develop along the margins or cracks.

Schizidia resemble phyllidia having flattened structures, but are formed by small parts flaking off the thallus surface. Therefore, their lower surface is not covered

by a thallus cortex and the remains of the thallus medulla are usually attached as residue. Schizidia are relatively rare and can be observed in terricolous lichens, e.g. *Baeomyces*, and within the cups of *Cladonia pyxidata*.

5.3 Other Surface Structures

Surface morphology of lichens varies considerably among species or even across individual thallus of the same species. Surface structures correlate with internal differentiation of the thallus, especially of the upper, cortical layers (Nash III et al. 2002).

Shiny surface is usually the result of highly gelatinized cortical hyphae. Some thalli have frosted appearance because of white granular deposits on the thallus surface, which is referred as *pruina*, and such thalli are described as *pruinose*. Pruina is usually crystallized calcium oxalate, crystallized lichen substances or the remains of dead partially disintegrated surface cells.

Pulverulent lichens have a powdery surface. *Pubescent* lichens have very fine hair (much finer than cilia or isidia) on their thallus surface. *Glabrous* lichens are without hair. The thallus surface texture can be *plane* (± flattened) or *undulate* (wavy). *Rugose* thallus has evenly thickened rounded wrinkles, called *rugae*. *Veins* are irregular net-like pattern, typical for the lower surface of foliose lichen species belonging to the genus *Peltigera*. Some lichens (e.g. *Nephroma*, *Peltigera*, *Sticta* and *Leptogium*) have a thick mat of hair-like hyphae, particularly on the lower surface, known as *tomentum*.

Mottled appearance of the thallus surface, found in *Parmelia*, *Parmotrema* and *Physcia* refer to as *maculae*, which are small rounded to irregularly elongated, pale spots caused by uneven thickening of the cortex and irregular distribution of photobiont cells below.

Cyphelloids are larger breaks in the thallus cortex, which are usually paler or more brightly coloured than the surrounding thallus and facilitate gas exchange. Two types of cyphelloids can generally be distinguished: (i) *cyphellae*, which only occur on the lower surface, e.g. *Sticta*, and are often imbedded in a tomentum; they are distinct recesses, sharply delimited, rounded or ovate, lined with a pseudocortex and surrounded by a pale ring and (ii) *pseudocyphellae*, which are more widely distributed and characteristic for several different terricolous genera (e.g. *Allocetraria*, *Bryoria*, *Cetraria*, *Flavocetraria*, *Melanelia*, *Parmelia*, *Pseudocyphellaria* and *Ramalina*); they are plane to slightly convex structures where medullary hyphae break through the thallus cortex. Pseudocyphellae occur in various shapes and can be found on the upper surface (e.g. *Parmelia*, *Melanelia*, *Melanelixia*), marginal (e.g. *Allocetraria*, *Cetraria*, *Ramalina*), on the lower surface (e.g. *Flavocetraria*) and on the thallus surface of fruticose lichens (e.g. *Bryoria*).

Raised surface features vary from rounded *papillae* (e.g. *Allocetraria*, *Melanelia*) (< 0.3 mm in diameter) to *pustules* (e.g. *Collema*, *Flavoparmelia*, *Hypotrachyna*), which are larger (up several millimetre wide) than papillae and are convex, blister-like bulges on the upper side of foliose lichens, each with a corresponding

depression on the lower surface. *Verrucose* thallus surface is characterized by *tubercles* or *verrucae*, which are relatively large (± 1 mm), conspicuous, rounded, wart-like outgrowths (e.g. *Collema*, *Cladonia*, *Lempholemma*, *Stereocaulon*, *Umbilicaria*).

Lichen thallus develops pits, depressions, channels and furrows without causing breaking of the thallus surface. A shallower and coarser pattern is called *scrobiculate* (e.g. *Nephroma*, *Peltigera*). Shallowly grooved or channelled depressions are called *sulcae* (e.g. *Parmelia sulcata*).

Cephalodia are unique, small, gall-like (0.5-1 mm wide) surface structures, which occur in tripartite lichen symbioses where the lichen fungus associates with both green algae (as primary photobiont) and cyanobacteria (as secondary photobiont). Sometimes they are externally formed as warty, squamulose or shrubby outgrowths of the thallus surface (e.g. *Nephroma*, *Peltigera*, *Stereocaulon*). However, in other lichens, they form internally and can only be noticed as a discoloration or when viewed in thallus cross sections (e.g. *Peltigera*).

6 Anatomy of the Lichen Thallus

Thallus anatomy of terricolous lichens varies extensively from highly differentiated thalli with several distinct layers of hyphae to thalli with virtually no internal differentiation. Thalli can be classified into two types. (i) *Homoiomerous*, in which the photobiont and the mycobiont are loosely interwoven with uniform dispersal of photobiont cells, throughout the thallus (e.g. *Collema*, *Leptogium*). Homoiomerous thalli are most commonly formed with cyanobacteria, and some of these lichens swell enormously if wetted with water. More frequently, lichen thalli are (ii) *Heteromerous*, where their thallus anatomy is stratified into distinct layers, especially an algal layer which may be distinguished from one or more *cortical* layers and a *medulla* (e.g. *Allocetraria*, *Bryoria*, *Bulbothrix*, *Cladia*, *Coccocarpia*, *Evernia*, *Heterodermia*, *Hypogymnia*, *Melanelixia*, *Nephroma*, *Peltigera*, *Phaeophyscia*, *Physcia* and *Sticta*).

7 Fruiting Bodies

Sexual reproduction in terricolous lichens occurs through ascospores, which are produced in fruiting bodies (ascocarps). Following ascocarps are reported from Indian terricolous lichens (Nash III et al. 2002).

7.1 Apothecia

They are disc-shaped structures formed by the lichen fungus on the thallus surface. Two important parts of an apothecium are the margin and the disc. The margin of an apothecium forms a ring around the disc of the apothecium. The disc is the

layer in the fruiting body where fungal spores are produced. The margin can appear similar in structure and colour to the thallus or to the disc. If the margin is similar to the thallus, it is called thalline margin and the whole apothecium is referred to as *Lecanorine apothecium* (named after *Lecanora*), whereas when the margin appears strongly blackened and rather similar to the disc, it is referred to as *Lecideine apothecia* (named after *Lecidea*). *Biatorine apothecia* (named after *Biatora*) have similar margins to the disc, but not strongly blackened.

7.2 Perithecia

They are flask-shaped fruiting bodies containing the asci. At maturity, an opening at the top, the ostiole, allows release of the spores. Perithecia are fully or partially immersed in the thallus or in the substrate, are rarely more than 1 mm in diameter, and occur in small numbers. They may be scattered or grouped, sometimes in clusters or in discrete areas of blackened tissue, a stroma. The walls of the perithecium, commonly black or darkened, form the exciple (or excipulum), which may be partly covered by a shield-like structure—*the involucrellum*. Lichens having perithecium are termed "pyrenocarpous" and common examples are *Agonimia*, *Catapyrenium*, *Dermatocarpon*, *Endocarpon*, *Placidium*. Their identification commonly requires a vertical section of the perithecium to elucidate the structure of the exciple, the involucrellum (if any), and the arrangement of the tissues within, as well as details of the asci and spores.

7.3 Pycnoconidia

Conidium is a specialized, non-motile fungal spore, which develops externally from specialized conidiogenous cells, in pycnidia in some terricolous lichens (e.g. *Flavoparmelia*, *Flavopunctelia*, *Hypogymnia*, *Melanelixia*, *Parmelinella*, *Rhizoplaca*, *Umbilicaria*). These spores (pycnoconidia) are often believed to be the male spermatia of the lichens, but some can also germinate and form new lichens.

8 Ascospores (Spores)

Ascospores vary in size, shape and structure and may be colourless or brown. Spore shape and size are important taxonomic characters for generic segregation in terricolous lichens. There are usually eight spores in each ascus; however, in some genera, the number of spores can be in 100s or in multiples of eight (16, 32 etc). Terricolous lichens show a wide range of sexually formed ascospore forms, from simple spores (without any septa) to spores with a single septa or with several septa (*pluriseptate*). Pluriseptate spores are formed in genera *Peltigera*, *Stereocaulon* etc. Simple spores also show diversity in forms, such as clavate, oblong, ovoid, bacilliform, globose, subglobose, ellipsoid, and are found in large number of families like *Acarosporaceae*, *Cladoniaceae*, *Lichinaceae* and *Parmeliaceae*. Spores become *submuriform* if

longitudinal septa are occasionally formed between the transverse septa. *Muriform* spores always have several transverse as well as longitudinal septa. Submuriform to muriform spores are represented by some genera like *Collema*, *Leptogium* and *Diploschistes*. Some other types of spores are also formed in terricolous lichens, like *polaribilocular* spores, which have a thick median cross wall formed by "isthmus" and are hyaline and characteristic of the genus *Teloschistes*, *Pachysporaria*-type (spores with strongly thickened walls around rounded cell lumina), *Physcia*-type and *Physconia*-type spores are characteristic of the family *Physciaceae*.

9 Conservation Status of Terricolous Lichens in India

Terricolous lichens face the same threats as other lichen groups, which range from natural climate change, unsustainable utilization for commercial purposes, zoo-anthropogenic pressures and unsustainable management of lichen-rich habitats (Upreti 1995; Scheidegger and Clerc 2002). As growth of soil lichens is intimately linked with stability of soil crust, any change/pressure on the terrestrial niches is exemplified by soil lichens, which are very sensitive to zoo-anthropogenic pressures (Rai et al. 2012). Terricolous lichens in India are the most vulnerable group of lichens, and substrate shift is very evident in this group which perishes on onset of even a slight disturbance. As the largest diversity of terricolous lichens in India occurs in Himalayan habitats, mainly in temperate–alpine grasslands (Bugyals), these habitats must be managed in sustainable way for healthy survival of soil lichens. The major threat to soil lichens is grazing and cattle-induced trampling, which can be minimized by decreasing the annual frequency of grazing in specific area and checks on period of grazing and number of cattle. The alpine grasslands are also faced with pilgrimage-based tourism in India, as these regions have some of the major temples of Hindu belief (e.g. Tungnath, Badrinath, Jageshwar), which induce pressures on soil crust because of tourist movements. The pressures can be reduced my construction of approach pathways for tourist movement. The terricolous lichens can only flourish in habitats where there is minimal competition with other ground vegetation (Scheidegger and Clerc 2002); therefore, agricultural practices like manure addition in areas of terricolous lichens, which increase the flourishing of other vascular plants and thus increase competition, can result in decrease in soil lichens.

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Chapter 2
Terricolous Lichens of India: Taxonomic Keys and Description

Himanshu Rai, Roshni Khare, Dalip Kumar Upreti and Teuvo Ahti

1 Introduction

The current taxonomic account of terricolous lichens is based on investigations of specimens preserved in CSIR-National Botanical Research Institute herbarium (LWG); Lucknow University, Lucknow herbarium (LWG-LWU) and personal collection of Dr D. D. Awasthi (LWG-AWAS) preserved in LWG; lichen herbarium of Botanical Survey of India, Sikkim Himalayan circle, Gangtok, Sikkim (BSHC) and eastern circle, Shilong, Meghalaya (ASSAM); herbarium of National Museum of Nature and Science, Tsukuba, Ibaraki Prefecture, Japan (TNS); herbarium of University of Helsinki (H) and terricolous lichens taxa reported so far in different literature within the present political boundaries of India.

Lichen samples were examined morpho-anatomically using thin hand-cut sections of apothecia and thalli mounted in plain water, lactophenol cotton blue, 5% KOH and iodine solution and observed under a compound microscope. The specimens were examined with a LEICA™ S8 APO stereomicroscope fitted with camera attachment (LEICA™ 10445929 0.5X) and LEICA™ DM 500 optical microscope. Photographs were taken by using FUJIFILM™ Fine Pix S5800 S800 camera and camera attachment of stereomicroscope. The external morphology was examined generally in dry conditions but dark brown to bluish specimens of cyanolichens *Leptogium* and *Collema* were studied in wet conditions. The colours of medulla, epithecium, hypothecium and ascus were recorded. The asci and ascospores were taken from the sections when mounted in water, and their shapes and sizes were recorded. The

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Teuvo Ahti has contributed only for genus *Cladonia*

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chemistry of lichens was studied using spot tests, thin layer chromatography (TLC), microcrystallography and ultraviolet (UV) reaction of lichen thallus (Chap. 1, Vol. 2). All the lichen taxa thus studied were compared with relevant literature (i.e. checklist, revisionary studies, flora and monographs), in order to identify lichen samples up to species level (Singh and Upreti 1984; Purvis et al. 1992; Goward et al. 1994; Goward 1999; Ahti 2000; Divakar and Upreti 2005; Awasthi 2007; McCune and Rosentreter 2007; Rosentreter et al. 2007; Saag et al. 2009; Upreti et al. 2010; Singh and Sinha 2010; Upreti and Divakar 2010). New records of terricolous lichen species were recorded against the annotated checklist by Singh and Sinha (2010).

2 Present Status of Terricolous Lichen Diversity in India

The present study concludes occurrence of 312 species of terricolous lichens belonging to 79 genera and 28 families (Table 2.1). Out of these, about 19 species (6.1%) are endemic. Species diversity at family level shows that *Parmeliaceae* (70 species) dominates, followed by *Cladoniaceae* (61 species) and *Collemataceae* (38 species) (Table 2.2). Similarly, at generic level, maximum diversity is shown by *Cladonia* (59 species), followed by *Leptogium* (20 species), *Collema* (18 species), *Peltigera* (17 species) and *Heterodermia* (11 species) (Table 2.2).

Considering diversity of terricolous lichens in different Lichenogeographic regions, it may be concluded that Western Himalaya are the most diverse in terricolous lichens, holding 225 species, followed by Eastern Himalaya and Northeast India (164 species), Eastern Ghats and Deccan plateau (51 species), and Western Ghats (21 species) (Fig. 2.36). Andaman and Nicobar region is devoid of any records of terricolous lichen. Maximum endemism of terricolous lichens were found in Central India (50%), followed by Western Dry Regions (20%).

The study elucidated seven species as new records for India.

1. *Bryoria nepalensis* D. D. Awasthi
2. *Umbilicaria leiocarpa* DC
3. *Pertusaria puffina* A. W. Archer and Elix
4. *Buellia asterella* Poelt and Sulzer
5. *Peltigera lepidophora* (Nyl.) Bitter
6. *Leptogium teretiusculum* (Flörke in Wallr.) Arnold
7. *Pseudocyphellaria ceylonensis* H. Magn

3 Taxonomic Description

All the identified lichens are artificially keyed out first in genera and ultimately identified species are keyed under their respective genera. Genera under each family and species under each genus are arranged alphabetically. Data regarding the total number of species in the world under each genus is taken from latest references (Singh and Sinha 2010; Nash et al. 2002). Outline classification of Ascomycota is

Table 2.1 A conspectus of families, genera and species of terricolous lichens in India

Sr. No.	Name of family	Names of genera	No. of genera	No. of species
1.	***Acarosporaceae***	ACAROSPORA A. Massal.	**1**	**3**
2.	***Baeomycetaceae***	BAEOMYCES Pers.	**1**	**2**
3.	***Caliciaceae***	ACROSCYPHUS Lév.	**2**	**1**
		BUELLIA De Not.		**1**
4.	***Candelariaceae***	CANDELARIELLA Müll. Arg.	**1**	**1**
5.	***Catillariaceae***	TONINIA A. Massal.	**1**	**3**
6.	***Cladoniaceae***	CLADIA Nyl	**3**	**1**
		CLADONIA P. Browne		**59**
		GYMNODERMA Nyl.		**1**
7.	***Coccocarpiaceae***	COCCOCARPIA Pers.	**1**	**3**
8.	***Collemataceae***	COLLEMA Weber ex F.H. Wigg.	**2**	**18**
		LEPTOGIUM (Ach.) Gray		**20**
9.	***Icmadophilaceae***	DIBAEIS Clem.	**4**	**2**
		ICMADOPHILA Trevis.		**1**
		SIPHULA Fr.		**1**
		THAMNOLIA Ach. ex Schaer.		**1**
10.	***Lecanoraceae***	LECANORA Ach.	**2**	**2**
		RHIZOPLACA Zopf		**2**
11.	***Lecideaceae***	LECIDOMA G. Schneider and Hertel	**1**	**1**
12.	***Lichinaceae***	HEPPIA Nägeli ex A. Massal.	**3**	**1**
		LEMPHOLEMMA Körb.		**1**
		PECCANIA A. Massal. ex Arnold		**3**
13.	***Lobariaceae***	LOBARIA (Schreb.) Hoffm.	**3**	**4**
		PSEUDOCYPHELLARIA Vain.		**1**
		STICTA (Schreb.) Ach.		**10**
14.	***Megasporaceae***	LOBOTHALLIA (Clauzade and Cl. Roux) Hafellner	**1**	**1**
15.	***Nephromataceae***	NEPHROMA Ach.	**1**	**4**
16.	***Pannariaceae***	FUSCOPANNARIA P.M. Jørg.	**1**	**2**
17.	***Parmeliaceae***	ALECTORIA Ach.	**26**	**1**
		ALLOCETRARIA Kurok. and M.J. Lai		**4**
		BRYORIA Brodo and D. Hawksw.		**8**
		BULBOTHRIX Hale		**2**
		CETRARIA Ach.		**6**
		CETRELIA W.L. Culb. and C.F. Culb.		**2**
		EVERNIA Ach.		**1**
		EVERNIASTRUM Hale ex Sipman		**3**
		FLAVOCETRARIA Kärnefelt and A. Thell		**2**
		FLAVOCETRARIELLA D.D. Awasthi		**2**
		FLAVOPARMELIA Hale		**1**
		FLAVOPUNCTELIA (Krog) Hale		**1**
		HYPOGYMNIA (Nyl.) Nyl.		**4**
		HYPOTRACHYNA (Vain.) Hale		**4**
		LETHARIELLA (Motyka) Krog		**2**
		MELANELIA Essl.		**2**
		MELANELIXIA O. Blanco and al.		**2**

Table 2.1 (continued)

Sr. No.	Name of family	Names of genera	No. of genera	No. of species
		MELANOHALEA O. Blanco and al.		**1**
		NEPHROMOPSIS Müll. Arg.		**2**
		PARMELIA Ach.		**2**
		PARMELINELLA Elix and Hale		**1**
		PARMOTREMA A. Massal.		**9**
		PUNCTELIA Krog		**2**
		TUCKNERARIA Randlane and A. Thell		**1**
		USNEA Dill. ex Adans.		**1**
		XANTHOPARMELIA (Vain.) Hale		**4**
18.	***Peltigeraceae***	PELTIGERA Willd.	**2**	**17**
		SOLORINA Ach.		**3**
19.	***Pertusariaceae***	PERTUSARIA DC.	**1**	**1**
20.	***Physciaceae***	ANAPTYCHIA Körb.	**6**	**2**
		HETERODERMIA Trevis. em. Poelt		**11**
		PHAEOPHYSCIA Moberg		**4**
		PHYSCIA (Schreb.) Mich.		**4**
		PHYSCONIA Poelt		**3**
		RINODINA (Ach.) Gray		**2**
21.	***Psoraceae***	PSORA Hoffm.	**1**	**2**
22.	***Ramalinaceae***	FRUTIDELLA Kalb	**2**	**1**
		RAMALINA Ach.		**4**
23.	***Stereocaulaceae***	LEPRARIA Ach.	**3**	**5**
		SQUAMARINA Poelt		**1**
		STEREOCAULON (Schreb.) Hoffm.		**13**
24.	***Teloschistaceae***	TELOSCHISTES Norman	**1**	**1**
25.	***Thelotremataceae***	DIPLOSCHISTES Norman	**1**	**4**
26.	***Umbilicariaceae***	UMBILICARIA Hoffm.	**1**	**4**
27.	***Verrucariaceae***	AGONIMIA Zahlbr.	**5**	**1**
		CATAPYRENIUM Flot.		**1**
		DERMATOCARPON Eschw.		**1**
		ENDOCARPON Hedw.		**1**
		PLACIDIUM A. Massal.		**2**
28.	***Lecanorales***[a]	LEPROCAULON Nyl. ex Lamy	**2**	**2**
		MYCOBILIMBIA Rehm		**2**
		Total	**79**	**312**

[a] The genera and species included in this order are with uncertain families

followed as given by Lumbsch and Huhndorf (2009), and current name of species was validated using the study by Singh and Sinha (2010). Citation of relevant literature for taxonomic nomenclature are followed that from Awasthi (2007) and Singh and Sinha (2010). Each species is described with respect to its morphological, anatomical and chemical characters if any. Ecology of the species is described with reference to their habitat differentiation assigned according to Scheidegger and Clerc (2002) (Chap. 1). Besides the reported distribution of the taxa within Indian states,

Table 2.2 Dominant families and genera of terricolous lichens in India

Dominant families		Dominant genera	
Family	No. of species	Genus	No. of species
Parmeliaceae	70	*Cladonia*	59
Cladoniaceae	61	*Leptogium*	20
Collemataceae	38	*Collema*	18
Physciaceae	28	*Peltigera*	17
Peltigeraceae	20	*Heterodermia*	11
Stereocaulaceae	19	*Stereocaulon*	13
Lobariaceae	15	*Sticta*	10
Verrucariaceae	6	*Parmotrema*	9
Icmadophilaceae	5	*Bryoria*	8
Lichinaceae	5	*Cetraria*	6
Ramalinaceae	5	*Lepraria*	5
Lecanoraceae	4	*Allocetraria*	4
Nephromataceae	4	*Diploschistes*	4
Acarosporaceae	3	*Hypogymnia*	4
Catillariaceae	3	*Hypotrachyna*	4
Coccocarpaceae	3	*Lobaria*	4
Caliciaceae	2	*Nephroma*	4
Pannariaceae	2	*Phaeophyscia*	4
Baeomycetaceae	2	*Physcia*	4
Psoraceae	2	*Ramalina*	4
Lecidiaceae	1	*Umbilicaria*	4
Pertusariaceae	1	*Xathoparmelia*	4
Megasporaceae	1		
Teloschistaceae	1		

their distribution outside India is provided as far as possible. Distribution of a taxon begins with India, comprising Indian states within paranthesis, then followed by other countries, regions, continents and general remarks if any. These are arranged in alphabetical order and separated by semicolon (;). The taxa with limited distribution within India, which include several recently described species as well, are treated as endemic until reported from elsewhere. Illustrative distribution maps and photographs of species are also given to facilitate identification.

Key to the terricolous lichen genera of India:

1.	Thallus foliose, fruticose, subfruticose or dimorphic	2
1a.	Thallus leprose, crustose or squamulose, subfoliose-squamulose, subcrustose-squamulose	67
2.	Thallus foliose, fruticose or subfruticose	3
2a.	Thallus dimorphic	61
3.	Thallus foliose	4
3a.	Thallus fruticose to subfruticose	45
4.	Thallus with blue green alga as photobiont	5
4a.	Thallus with green alga as photobiont	14