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Research Paper

Contributions to the Floral Diversity of Schirmacher Oasis and Larsemann Hills, Antarctica

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In continental Antarctica, algae, fungi, lichen and mosses are the major floristic elements. To understand their distribution and diversity pattern in ice free areas of Schirmacher Oasis and Larsemann Hills investigations were conducted during various Indian Antarctic Expeditions. Due to the extreme environmental conditions in Antarctica, lichens and bryophytes undergo sever morphological changes and occur in mostly in sterile condition that makes them difficult group to identify. A total of 69 species of lichens were encountered in the Schirmacher Oasis and 25 species in the region of Larsemann Hills. Most lichens known from these two areas are microlichens. The ecophysiological studies on lichens indicated *Rhizoplaca melanophthalma* as the most desiccation tolerant species in Schirmacher Oasis. The studies on moss flora contributed only 12 species under eight genera and five families from Schirmacher Oasis. The sub-fossil moss *Pohlia nutans* of Holocene period was recorded from lake sediment cores from Schirmacher Oasis. There are several studies on algal flora of Schirmacher Oasis and in one of the studies a total of 109 species of cyanobacteria belonging to 30 genera and 9 families were recorded from Schirmacher Oasis. Similarly, a total of 19 species of fungi belonging to 13 genera and seven families were recorded from Schirmacher Oasis soils and 5 species of yeasts were recorded from Larsemann Hills. Furthermore, *Thelebolus microsporus* was characterized for adaptation strategies and biotechnological potentials.

Keywords: Schirmacher Oasis; Larsemann Hills; Algae; Fungi; Moss; Lichens; Antarctica

Introduction

Antarctica is a region that has extreme environmental conditions for the existence of any form of life. The extremes include low temperature, long periods of darkness, frost and snow cover, frequent winds, bright sun light along with UV radiation. Only 0.3% of the area of Antarctica is ice-free during summer period and Antarctic life is mainly confined to this ice-free areas of coastal outcrops, offshore islands, nunataks, mountain ranges and oases. The occurrence of life in Antarctica can be directly attributed to their adaptation to the stress. Therefore, assessment of terrestrial biodiversity is a thrust area of research for understanding the survival strategy in extreme environment and for the prospect of biotechnology in Antarctica. Indian researchers have contributed immensely to the terrestrial biodiversity of Antarctica since their first expedition to the continent during the year 1981. Their area of operation is mainly centered on Schirmarcher Oasis and Larsemann Hills in east Antarctica. In the present communication we summarize the Indian contribution to terrestrial biodiversity of Antarctica with emphasis on algae (including Cyanobacteria), fungi, moss and lichens.

Contributions to the Lichenological Studies

Lichen is a symbiotic association between an alga and a fungus. The extraordinary ability of the lichens to thrive in freezing temperatures, UV exposre and oligotrophic soils and highly diffused sunlight gives

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them the edge over the other flora in colonizing one of the world's most inhospitable continents. The dry and sterile rock surfaces where other group of plants unable to grow the lichens colonizes successfully on them (Fig. 1A). Therefore, the ecology, taxonomy and adaptation biology of lichen are always been a subject

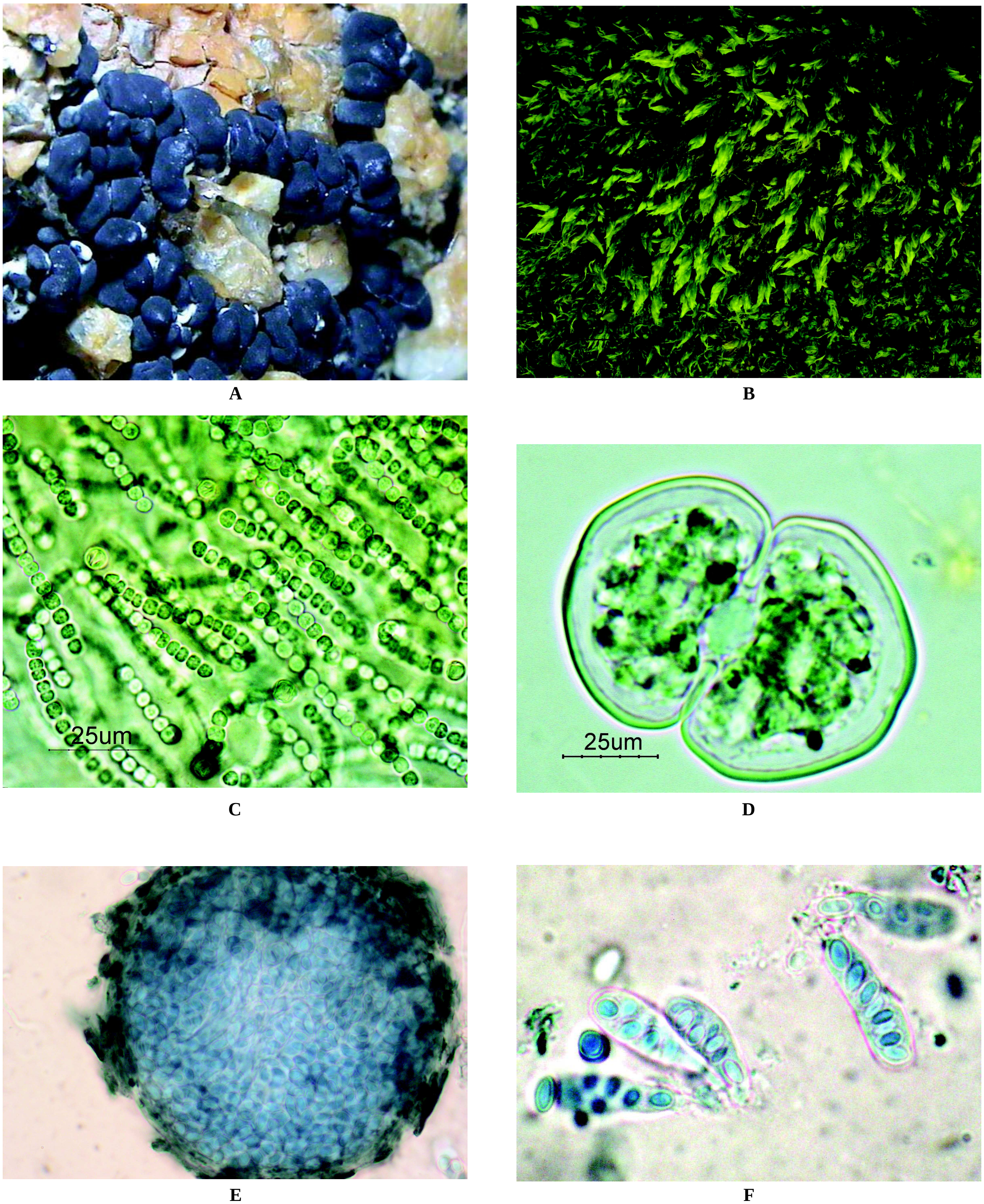

Fig. 1: (A) *Lecidea* (lichen), (B) *Bryum* (Moss), (C) *Nostoc* (Cyanobacteria), (D) *Cosmarium* (green alga) and (E-F) *Thelebolus* (fungi)

Table 1: Lichens flora of Schirmacher Oasis & Larsemann Hills, Antarctica

Species	Contributors
Acarospora sp. A. Massal	Wafar & Untawale, 1983; Upreti 1997
Acarospora flavocordia Castello & Nimis	Olech & Singh, 2010
Acarospora gwynnii Dodge & Rudolph	Upreti & Pant 1995; Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Acarospora williamsi Filson	Upreti & Pant 1995; Olech & Singh, 2010
Amandinea coniops (Wahlenb.) M. Choisy ex Scheid	Olech & Singh, 2010
Amandinea punctata (Hoffm.) Coppins & Scheid	Olech & Singh, 2010
Alectoria minuscula	Upreti & Pant 1995
Arthonia lapidicola (Taylor) Branth & Rostr.	Singh *et al*., 2007
Arthonia molendoi (Frauenf.) R. Sant.	Olech & Singh, 2010
Arthonia rufidula (Hue) D. Hawksw., R. Sant. & Øvstedal	Olech & Singh, 2010
Bacidia johnstonii C. W. Dodge	Olech & Singh, 2010
Bacidia stipata I. M. Lamb	Olech & Singh, 2010
Buellia darbishirei I. M. Lamb	Olech & Singh, 2010
Buellia frigida Darb.	Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Buellia grimmiae Filson	Upreti & Pant 1995; Upreti 1996; Singh *et al*., 2007; Olech & Singh, 2010
Buellia grisea C. W. Dodge & G. E. Baker	Olech & Singh, 2010
Buellia illaetabilis I.M. Lamb	Nayaka & Upreti 2005; Singh *et al*., 2013
Buellia lignoides Filson	Olech & Singh, 2010
Buellia pallida C. W. Dodge & G. E. Baker	Upreti & Pant 1995; Upreti 1996; Olech & Singh, 2010
Buellia papillata (Sommerf.) Tuck.	Olech & Singh, 2010
Buellia pycnogonoides Darb.	Olech & Singh, 2010
Buellia subfrigida May. Inoue	Olech & Singh, 2010
Caloplaca athallina Darb.	Singh *et al*., 2007; Olech & Singh, 2010
Caloplaca citrina (Hoffm.) Nordin	Singh *et al*., 2007; Olech & Singh, 2010
Caloplaca frigida Søchting	Olech & Singh, 2010
Caloplaca isidioclada Zahlbr.	Upreti & Pant 1995
Caloplaca lewis-smithii Søchting & Øvstedal	Singh *et al*., 2007; Olech & Singh, 2010
Caloplaca saxicola (Hoffm.) Nordin	Singh *et al*., 2007; Olech & Singh, 2010
Candelaria murrayi Poelt	Olech & Singh, 2010
Candelariella flava (C. W. Dodge & G. E. Baker) Castello & Nimis	Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Carbonea assentiens (Nyl.) Hertel,	Nayaka & Upreti 2005; Singh *et al*., 2013
Carbonea capsulate (Dodge & Baker) Hale	Upreti & Pant 1995; Upreti 1996
Carbonea vorticosa (Flörke) Hertel (Flörke) Hertel	Singh *et al*., 2007; Olech & Singh, 2010; Singh *et al*., 2013
Huea coralligera (Hue) C.W. Dodge & G.E. Baker	Singh *et al*., 2007
Lecania cf. racovitzae (Vain.) Darb.	Olech & Singh, 2010
Lecanora cf. mawsonii C. W. Dodge	Olech & Singh, 2010
Lecanora expectans Darb.	Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Lecanora fuscobrunnea C. W. Dodge & G. E. Baker	Upreti & Pant 1995; Upreti 1997; Olech & Singh, 2010
Lecanora geophila (Th. Fr.) Poelt	Nayaka & Upreti 2005; Singh *et al*., 2007; Olech & Singh, 2010; Singh *et al*., 2013
Lecanora mons-nivis Darb.	Olech & Singh, 2010
Lecanora orosthea (Ach.) Ach.	Olech & Singh, 2010; Singh *et al.*, 2013
Lecanora sverdrupiana Øvstedal	Olech & Singh, 2010
Lecidea andersonii Filson	Olech & Singh, 2010; Singh *et al*., 2013
Lecidea cancriformis C. W. Dodge & G. E. Baker	Upreti & Pant 1995; Upreti 1996; Singh *et al*., 2007; Olech & Singh, 2010
Lecidea cf. placodiiformis Hue	Olech & Singh, 2010
Lecidea siplei R. Filson	Upreti & Pant 1995; Upreti 1996
Lecidella siplei (C. W. Dodge & G. E. Baker) May. Inoue	Olech & Singh, 2010; Singh *et al*., 2007
Lecidella patavina (A. Massal.) Knoph & Leuckert	Singh *et al*., 2007
Lecidella stigmatea (Ach.) Hertel	Nayaka & Upreti 2005; Olech & Singh, 2010; Singh *et al*., 2013
Lepraria cacuminum (A. Massal.) Lohtander	Olech & Singh, 2010; Singh *et al*., 2013
Lepraria membranacea (Dicks.) Lett.	Upreti & Pant 1995
Leproloma cacuminum	Nayaka & Upreti 2005; Singh

(A. Massal.) J.R. Laundon	*et al*., 2013
Pertusaria sp.	Upreti & Pant 1995
Physcia caesia (Hoffm.) Fürnr.	Upreti & Pant 1995; Olech & Singh, 2010; Singh *et al*., 2007
Physcia dubia (Hoffm.) Lettau	Singh *et al*., 2007; Olech & Singh, 2010
Pleopsidium chlorophanum (Wahlenb.) Zopf	Olech & Singh, 2010
Polycaulina murrayi Dodge	Upreti & Pant 1995
Porpidia sp.	Upreti & Pant 1995
Pseudephebe minuscule (Nyl. Ex Arnold) Brodo & D. Hawksw.	Singh *et al*., 2007; Olech & Singh, 2010; Singh *et al*., 2013
Rhizocarpon flavum Dodge & Baker	Upreti & Pant 1995; Upreti 1996
Rhizocarpon geminatum Körb.	Olech & Singh, 2010
Rhizocarpon geographicum (L.) DC.	Olech & Singh, 2010
Rhizocarpon nidificum (Hue) Darb.	Nayaka & Upreti 2005; Singh *et al*., 2013
Rhizoplaca melanophtalma (Ram.) Leuckert & Poelt	Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Rinodina endophragmia I. M. Lamb	Nayaka & Upreti 2005; Olech & Singh, 2010; Singh *et al*., 2013
Rinodina olivaceobrunnea C. W. Dodge & G. E. Baker	Upreti & Pant 1995; Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Rinodina peloleuca (Nyl.) Mull. Arg.	Singh *et al*., 2007
Rinodina petermanii (Hue) Darbishire	Upreti & Pant 1995
Sarcogyne privigna (Ach.) A. Massal.	Nayaka & Upreti 2005; Singh *et al*., 2007; Olech & Singh, 2010; Singh *et al.*, 2013
Umbilicaria africana (Jatta) Krog & Swinscow	Nayaka & Upreti 2005; Olech & Singh, 2010; Singh *et al*., 2013
Umbilicaria antarctica Frey & I. M. Lamb	Olech & Singh, 2010
Umbilicaria aprina Nyl.	Upreti & Pant 1995; Olech & Singh, 2010; Singh *et al.*, 2013
Umbilicaria decussta (Vill.) Zahlbr.	Upreti & Pant 1995; Singh *et al*., 2007; Olech & Singh, 2010; Singh *et al*., 2013
Usnea antarctica Du Rietz	Singh *et al*., 2007; Singh *et al*., 2013
Verrucaria holizoa Leight.,	Nayaka & Upreti 2005; Singh *et al*., 2013
Xanthoria candelaris	Singh *et al*., 2013
Xanthoria elegans (Link) Th. Fr.	Upreti & Pant 1995; Upreti 1997; Singh *et al*., 2007; Olech & Singh, 2010
Xanthoria mawsonii C. W. Dodge	Singh *et al*., 2007; Olech & Singh, 2010

of investigation to Antarctic researchers. In the past few decades a large number of lichenological investigations on Antarctic lichens were carried out that provided clear picture of diversity and distribution of lichens in the continent with 439 taxa (Øvstedal and Smith 2001, 2004). In Indian context, for the first time Wafar and Untawale (1983) reported the occurrence of *Acarospora* sp. at Antarctica. However, lichens from Schirmacher Oasis have been collected since the 1970s. Golubkova and Simonov (1972) published the first comprehensive list of 21 lichen taxa from Schirmacher Oasis. Thereafter, detailed lichenological investigations in Schirmacher Oasis were carried out by Ritcher (1990a, 1995), researchers at CSIR-National Botanical Research Institute, Lucknow and ESSO-National Centre for Antarctic and Ocean Research, Goa. Upreti & Pant 1995; Upreti (1996, 1997) and Nayaka *et al*. (2009, 2011) systematically compiled and enumerated a total of 48 lichen taxa so far reported from Schirmacher Oasis. Meanwhile a monograph containing a comprehensive account of the taxonomy, ecology and distribution of lichens in the Schirmarcher Oasis has been published, according to which the region shelters a total of 54 lichenized and lichenicolous fungi (Olech and Singh, 2010). Upreti and Nayaka (2011) while reporting the affinities of Indian subcontinent lichen flora with that of Antractica mentioned that a total of 69 lichen taxa are so far known from Schirmacher Oasis. The species of lichen genus *Buellia* dominates the area with 10 species, followed by 9 species of *Lecanora*, 5 species each of *Caloplaca* and *Umbilicaria.* The crust forming species dominates the area with 54 species, while only 9 species are foliose, 4 are fruticose and single species of leprose form.

In the recent times India has extended its scope research at Larsemann Hills, in Prydz Bay area, East Antarctica. Singh *et al*. (2007) reported a total of 25 lichen species from McLeod island of Larsemann Hills 12 of which were new records to the area. The lichen biota of McLeod Island was dominated by crustose lichens with 19 species and *Buellia frigida* Darb. was the most dominant lichen. Singh *et al*. (2013) presented the consolidated checklist of lichens from both Schirmacher Oasis and Larsemann Hills. The check-list of lichen flora has been given in Table 1.

The lichens have ability that they can accumulate

Table 2: Bryoflora of Schirmacher Oasis, Antarctica

Species	Contributors
Bryum archangelicum Bruch & Schimp.	Ochyra & Singh 2008
B. argenteum Hedw.	Singh & Semwal 2000
B. argenteum Hedw. var. *muticum* Brid.	Ochyra & Singh 2008
B. orbiculatifolium Cardot & Broth.	Ochyra & Singh 2008
B. pseudotriquetrum (Hedw.) Gaertn.	Singh & Semwal 2000; Ochyra & Singh 2008
Bryoerythrophyllum recurviroste (Hedw.) Chen	Singh & Semwal 2000
Ceratodon purpureus (Hedw.) Brid., Bryol. Univ.	Singh & Semwal 2000; Ochyra & Singh 2008
Grimmia sp.	Singh & Semwal 2000
Grimmia plagiopodia Hedw.	Singh *et al*., 2012; Kurbatova & Ochyra 2012
Hennediella antarctica (Ångstr.) Ochyra & Matteri	Singh *et al*., 2012; Kurbatova & Ochyra 2012
Hennediella heimii (Hedw.) R.H. Zander	Singh *et al*., 2012
Leptobryum pyriforme (Hedw.)	Tewari & Pant 1986
Orthogrimmia sessitana (De Not.) Ochyra & Ż arnowiec	Ochyra & Singh 2008
Plagiothecium orthocarpum Mitt.	Singh *et al*., 2012
Pohlia nutans (Hedw.) Lindb.	Singh *et al*., 2012
Pottia heimii (Hedw.) Hamp.	Singh & Semwal 2000
Schistidium antarctici (Cardot) L.I. Savicz & Smirnova	Singh *et al*., 2012
Syntrichia sarconeurum Ochyra & R.H. Zander)	Singh *et al*., 2012

Table 3: Diatom flora of Schirmacher Oasis, Antarctica

Species	Contributors
Achnanthes minutissima (Kuetz.) Grunov.	Palanisamy 2010; Singh *et al*., 2013
Achnanthes exigua Grunov.	Palanisamy 2010; Singh *et al*., 2013
Diadesmis contenta (Grunov. Ex Heurck) D.G. Mann	Palanisamy 2010; Singh *et al*., 2013
Fragilaria intermedia Grunov.	Palanisamy 2010; Singh *et al*., 2013
Fragilaria intermedia Grunov. Var. *robusta* Venks	Palanisamy 2010; Singh *et al*., 2013
Fragilaria virescens Ralfs.	Palanisamy 2010; Singh *et al*., 2013
Gomphonema lanceolatum Ehrenb.	Palanisamy 2010; Singh *et al*., 2013
Hantzschia amphioxys (Ehrenb.) Grun.	Palanisamy 2010; Singh *et al*., 2013
Hantzschia sp.	Kashyap *et al*., 1988; Singh *et al*., 2013
Melosira sp.	Kashyap *et al*., 1988
Navicula cryptocephala Kuetz.	Palanisamy 2010; Singh *et al*., 2013
Navicula muticopsis Van Heurck.	Kashyap *et al*. 1988; Singh *et al*., 2013
Navicula radiiosa Kuetz.	Palanisamy 2010; Singh *et al*., 2013
Navicula sp. A & B	Singh *et al*., 2013
Nitzschia obtusa Gruan/W. Smith	Kashyap *et al*., 1988; Palanisamy 2010; Singh *et al*., 2013
Pinnularia borealis Ehrenb	Kashyap *et al*., 1988; Singh *et al*., 2013
Stauroneis anceps Ehrenb	Palanisamy 2010; Singh *et al*., 2013
Synedra ulna (Nitzsch.) Ehrenb.	Kashyap *et al*., 1988; Palanisamy 2007; Singh *et al*., 2013

Table 4: Cyanobacterial flora of Schirmacher Oasis, Antarctica

Anabaena sp.	Kashyap *et al*., 1988; Pandey *et al*., 2013
Anabaena cylindrica Lemm.	Singh *et al*., 2008
Aphanothece caldariorum Richter, P.	Singh *et al*., 2008
Aphanothece clathrata W. et. G. S. West	Singh *et al*., 2008
Aphanocapsa delicatissima W. et. G. S. West.	Singh *et al*., 2008
Aphanothece heterospora Rabenh.	Singh *et al*., 2008
Aphanocapsa montana Cramer	Singh *et al*., 2008
Aphanothece muscicola (Menegh.) Wille	Kashyap *et al*., 1988; Pandey *et al*., 1992; Singh *et al*., 2008
Aphanothece nidulance Richter	Kashyap *et al*., 1988
Aphanothece pallida (Kütz.) Rabenhorst	Singh *et al*., 2008
Aphanothece saxicola Nägeli.	Singh *et al*., 2008
Calothrix crustacea Thuret.	Singh *et al*., 2008
Calothrix cylindrica Fremy	Singh *et al*., 2008
Calothrix gelatinosa (Böcher) V. Poljanskij	Singh *et al*., 2008
Calothrix gracilis Fritsch.	Kashyap *et al*., 1988; Pandey *et al*., 1992
Calothrix parietina Thuret ex. Born et. Flah	Kashyap *et al*., 1988; Pandey *et al*., 1992; Singh *et al*., 2008
Calothrix braunii Born et. Flah.	Singh *et al*., 2008
Calothrix brevissima West	Kashyap *et al*., 1988; Pandey *et al*., 2013
Chamaesiphon subglobosus (Rostaf.) Lemm.	Kashyap *et al*., 1988; Pandey *et al*., 2013; Singh *et al*., 2008
Chlorococcum humicolum (Naeg.) Rabenh	Kashyap *et al*., 1988
Chroococcus aeruginosus Nag.	Kashyap *et al*., 1988; Pandey *et al*., 2013; Singh *et al*., 2008
Chroococcus limneticus var. *elegans* (Lem.) Hollerbach	Singh *et al*., 2008
Chroococcus minimus (Keissler) Lemm.	Singh *et al*., 2008
Chroococcus minutus (Kütz.) Näg.	Pandey *et al*. 2013; Singh *et al*., 2008
Chroococcus pallidus Näg.	Kashyap *et al*., 1988; Pandey *et al*., 2013; Singh *et al*., 2008
Chroococcus varius Braun	Singh *et al*., 2008
Chlorogloea microcystoides Geitler.	Singh *et al*., 2008
Cosmarium leave Riabenh	Kashyap *et al*., 1988
Cosmarium turgidum Breb	Kashyap *et al*., 1988
Cosmarium turpini Breb	Kashyap *et al*., 1988
Gloeocapsa sp.	Kashyap *et al*., 1988; Pandey *et al*., 1992
Gloeocapsa alpina (Näg.) Brand.	Singh *et al*., 2008
Gloeocapsa atrata (Turt.) Kütz.	Singh *et al*., 2008
Gloeocapsa fusco-lutea (Näg.) Kütz.	Singh *et al*., 2008
Gloeocapsa granosa (Berk.) Kütz.	Singh *et al*., 2008
Gloeocapsa kuetzingiana Näg.	Kashyap *et al*., 1988; Pandey *et al*. 2013; Singh *et al*., 2008
Gloeocapsa luteofusca Martens.	Singh *et al*., 2008
Gloeocapsa magma (Bréb.) Kütz.	Kashyap *et al*., 1988; Pandey *et al*. 1992; Singh *et al*., 2008
Gloeocapsa montana Kütz.	Singh *et al*., 2008
Gloeocapsa polydermatica Kütz.	Singh *et al*., 2008
Gloeocapsa ralfsiana (Harv.) Kütz.	Kashyap *et al*., 1988; Pandey *et al*., 1992; Singh *et al*., 2008
Gloeocapsa rupestris Kütz.	Singh *et al*., 2008
Gloeothece samoensis Wille.	Singh *et al*., 2008

Gloeocapsa sanguinea (Ag.) Kütz.	Singh *et al*., 2008
Lyngbya aestuarii Liebm. Ex Gomont	Kashyap *et al*., 1988; Pandey et al., 1992; Singh *et al*., 2008
Lyngbya attenuata Fritsch.	Kashyap *et al*., 1988; Pandey *et al*., 2013; Singh *et al*., 2008
Lyngbya aerugineo-coerulea (Kütz.) Gom.	Singh *et al*., 2008
Lyngbya confervoides Ag. ex. Gomont	Singh *et al*., 2008
Lyngbya infixa Fremy.	Singh *et al*., 2008
Lyngbya sp.	Singh *et al*., 2008
*Lyngbya lutea (*Ag.) Gom	Singh *et al*., 2008
Lyngbya martensiana Menegh.	Singh *et al*., 2008
Lyngbya nigra C. Ag. ex. Gomont.	Singh *et al*., 2008
Lyngbya semiplena (C. Ag.) J. Ag.	Singh *et al*., 2008
Microcoleus sociatus West et. West	Singh *et al*., 2008
Microcoleus vaginatus (Vauch.) Gom.	Singh *et al*., 2008
Nostoc sp.	Kashyap *et al*., 1988; Pandey *et al*., 1992
Nostoc antarcticum W. et G.S.West	Singh *et al*., 2008
Nostoc commune Vaucher ex Born et Flah	Kashyap *et al*., 1988; Pandey *et al*., 1992; Singh *et al*., 2008
Nostoc kihlmanii Lemm.	Singh *et al*., 2008
Nostoc pruniforme (Kütz.) Hariot.	Kashyap *et al*., 1988; Pandey *et al*., 2013; Singh *et al*., 2008
Nostoc sphaericum Vauchr	Pandey *et al*., 2013
Nostoc verrucosum Vaucher	Singh *et al*., 2008
Nodularia harveyana (Twaites) Thuret.	Singh *et al*., 2008
Myxosarcina chroococcoides Geitler	Singh *et al*., 2008
Oscillatoria agardhii Gomont.	Kashyap *et al*., 1988; Pandey *et al*., 2013
Oscillatoria anguina (Bory) Gom.	Singh *et al*., 2008
Oscillatoria animalis Agardh.	Singh *et al*., 2008
*Oscillatoria bornet*i var. *tenuis* Zukal	Singh *et al*., 2008
Oscillatoria brevis (Kütz.) Gomont.	Singh *et al*., 2008
Oscillatoria granulata Gardner	Singh *et al*., 2008
Oscillatoria irrigua Kütz.	Singh *et al*., 2008
Oscillatoria kuetlizii Lemm.	Kashyap *et al*., 1988; Pandey *et al*., 2013
Oscillatoria limosa Ag. Ex Gomont.	Kashyap *et al*., 1988; Pandey *et al*., 2013
Oscillatoria limnetica Lemm	Kashyap *et al*., 1988
Oscillatoria ornata Kütz.	Singh *et al*., 2008
Oscillatoria pseudogemminata Schmid.	Singh *et al*., 2008
Oscillatoria temuis Ag.	Kashyap *et al*., 1988
Phormidium automnale (Ag.) Gom	Kashyap *et al*., 1988
Phormidium fragile (Menegh) Gom	Kashyap *et al*., 1988
Phormidium frigidum Fritsch.	Kashyap *et al*., 1988; Pandey *et al*., 1992
Phormidium laminosum Gomont	Singh *et al*., 2008
Phormidium pristleyi F. E. Fritsch.	Singh *et al*., 2008
Phormidium molle	Singh *et al*., 2008
Phormidium mucosum Gardner.	Singh *et al*., 2008
Phormidium subincrustatum Fritsch and Rich.	Singh *et al*., 2008
Phormidium subfuscum Kütz. ex. Gomont	Singh *et al*., 2008

Phormidium tenue (Menegh.) Gomont	Singh *et al*., 2008
Phormidium uncinatum (Ag.) Gom	Singh *et al*., 2008
Phormidium viride (Vaucher) Lemm.	Singh *et al*., 2008
Plectonema gracillimum (Zopf) Hansgirg	Singh *et al*., 2008
Plectonema terebrans Born. et Flah.	Singh *et al*., 2008
Plectonema sp.	Pandey *et al*., 1992
Pleurocapsa minor Hansg.	Singh *et al*., 2008
Porphyrosiphon notarisii (Menegh.) Kütz.	Singh *et al*., 2008
Psudanabaena constricta (Szafer) Lauterb.	Singh *et al*., 2008
Rivularia minutula (Kütz.) Born et. Flah	Singh *et al*., 2008
Scenedesmus acutus Fritsch	Kashyap *et al*., 1988
Schizothrix antarctica F. E. Fritsch.	Singh *et al*., 2008
Schizothrix vaginata (Näg.) Gom.	Singh *et al*., 2008
Schizothrix sp. I & II	Kashyap *et al*., 1988; Pandey *et al*., 2013
Scytonema myochrous (Dillw.) Ag. ex. Born. et. Flah.	Pandey *et al*., 2013; Singh *et al*., 2008
Scytonema sp.	Kashyap *et al*., 1988; Pandey *et al*., 1992
Spirulina jenneri (Stiz.) Geitler	Singh *et al*., 2008
Stigonema minutum (Ag.) Hass. Ex Bornet et Flah.	Kashyap *et al*., 1988; Pandey *et al*., 1992; Singh *et al*., 2008
Synechococcus aeruginosus Nägeli.	Kashyap *et al*., 1988, Pandey *et al*., 1992; Singh *et al*., 2008
Synechocystis aquatilis Sauv.	Singh *et al*., 2008
Synechococcus cedrorum Sauv.	Singh *et al*., 2008
Synechococcus major Schröter.	Singh *et al*., 2008
Synechocystis pevalekii Erceg.	Singh *et al*., 2008
Synechocystis sallensis Skuja	Singh *et al*., 2008
Tolypothrix conglutinata Borz.	Kashyap *et al*., 1988; Pandey *et al*., 2013
Tolypothrix distorta (Kütz.) Born et Flah.	Singh *et al*., 2008
Tolypothrix byssoidea (Hass.) Kirchner ex Bornet et Flah.	Singh *et al*., 2008
Ulothrix sp.	Kashyap *et al*., 1988
Uronema sp.	Kashyap *et al*., 1988
Xenococcus sp. UN1	Singh *et al*., 2008

large amount of heavy metals in their thalli and act as an effective monitor of both for background and enhanced levels of heavy metals of the area. Antarctic lichens are also utilized for monitoring air pollution around Maitri by analyzing the heavy metals accumulated in them (Upreti and Pandey 1999). Heavy metal concentration in *Umbilicaria aprina* and *U. deccussata* growing luxuriantly were estimated for iron, copper, lead and chromium levels. The presence of lead in lichen samples collected near Russian station is quite interesting as it is mainly derived from man-made pollution, transported to the polar atmosphere owing to its use as an antiknock petrol additive. In one of the study pollen grains carried away by wind currents to Antarctica and deposited on moss and lichens tufts were analyzed that helped in tracing the direction of wind currents together with past climatic condition of the area. The encounter of different pollen and spore types reflected their long distance transport ranging from tropical to temperate floristic regions around Antarctica mainland which is devoid of any higher plant taxa, except for members of Poaceae and Caryophyllaceae (Sharma *et al*., 2002). In another study the carotenoid contents in lichens collected from Antarctica were also carried out by column and thin layer chromatography which revealed the presence of 21 carotenoids (Czeczuga *et al*., 1996). The total concentration of carotenoids

Table 5: Fungal flora of Schirmacher Oasis & Larsemann Hills, Antarctica

Species	Contributors
Schirmacher Oasis	
Acremonium antarcticum (Speg.) Howksw	Sharma 2000; Singh *et al*., 2013
Acremonium psychrophilum Moller & Gams	Sharma 2000; W. Singh *et al*., 2013
Acremonium zonatum (Swada) W. Gams	Singh *et al*., 2013
Arthrobotrys ferox Onofri & Tosi	Sharma 2000; Singh *et al*., 2013
Arthrobotrys robusta Duddington	Singh *et al*., 2013
Aspergillus fumigatus Fresenius	Singh *et al*., 2013
Bullera alba	Ray *et al*., 1989; Shivaji *et al*., 1994
Candida humicola	Ray *et al*., 1989; Shivaji *et al*., 1994
Candida famata	Ray *et al*., 1989; Shivaji *et al*., 1994
Candida ingeniosa	Ray *et al*., 1989; Shivaji *et al*., 1994
Candida auriculariae	Ray *et al*., 1989; Shivaji *et al*., 1994
Cephalosporium sp.	Singh *et al*., 2013
Cladosporium herbarum (Pers.) Link	Singh *et al*., 2013
Cryptoococcus friedmanii Vishniac	Singh *et al*., 2013
Cryptoococcus sp.	Sharma 2000; Singh *et al*., 2013
Cladosporium sp.	Singh *et al*., 2007
Dacrymyces sp.	Singh *et al*., 2013
Exidia sp.	Singh *et al*., 2013
Fusarium sp.	Singh *et al*., 2007
Hormoconis resinae Lind.	Singh *et al*., 2013
Mortierella antarctica Linne	Singh *et al*., 2013
Phoma exigua Desm.	Singh *et al*., 2013
Phoma herbarum Westd.	Sharma 2000; Singh *et al*., 2013
Rhodotorula rubra	Ray *et al*., 1989; Shivaji *et al*., 1994
Thelebolus microspores (Berk & Br.) Kim.	Singh *et al*., 2013
Trichoderma sp.	Singh *et al*., 2007
Torulopsis psychrophila	Sharma 2000; Singh *et al*., 2007; Singh *et al*., 2013
Torulopsis sake Goto	Singh *et al*., 2013
Larsemann Hills	
Cryptococcus albidus	Singh *et al*., unpublished
C. antarcticus	Singh *et al*., unpublished
Mrakia blollopis	Singh *et al*., unpublished
Rhodotorula sp.	Singh *et al*., unpublished
Thelebolus microsporus	Singh *et al*., 2013

raged from 23.25 to 123.50 μg^{-1} dry wt. The type of carotenoids in Antarctic lichens may provide the clue for the adaptation of lichens to harsh climatic condition.

During 28th Indian Antarctic Expedition, lichens of Schirmacher Oasis were studied in detail for their physiological adaptation to Antarctic environment. The water relation, carbon isotope discrimination and climate changes studies were conducted. According to the parameters of Pressure Volume Curve derived from Thermocouple Psychrometric technique *Rhizoplaca melanophthalma*, a squamulose lichen growing over soil in dry, exposed areas can be considered as highly desiccation tolerant species (Nayaka and Upreti, 2011). The detailed report of 28th expedition is under publication.

Contributions to the Bryophyte Flora

The bryophytic flora of Antarctica comprises about 85 species with dominance of moss with 70 taxa (Seppelt 1986). The bryophytes in the continent are confined to warmer regions such as peninsula and maritime region, while continental Antarctica is poorly represented. After lichens bryophytes are the better adapted plant groups to Antarctic conditions. The mosses (Fig. 1B) in Antarctica act like keystone species providing shelter to several other organisms such as micro-invertebrates, fungi, algae and lichens. Mosses are also sensitive to changes in the cryosphere. Their presence is an indicator of short term climatic and aerodynamic stability or the dynamics of snow and ice in the rock deserts of Oasis (Richter 1990b).

A large number of moss samples were collected from Schirmacher Oasis during 16th and 19th Indian Antarctic Expeditions which resulted in six species of bryophytes (Singh *et al*., 2013). Remarkable morphological variation and infertile condition makes identification of mosses difficult. Probably this is the reason why number of taxa are reduced to six from nine originally identified by Singh and Semwal (2000) from Schirmacher Oasis. Meanwhile, three remarkable new moss species (*Bryum argenteum*, *B. orbiculatifolium*, *B. archangelicum*) were added to terrestrial flora of Oasis (Ochyra and Singh, 2008). Recently, Singh *et al*. (2012) conducted a systematic survey and collected moss specimens from different terrestrial locations and lake sediments of Schirmacher Oasis which resulted in 12 species belonging to eight genera and five families. The check-list of moss flora has been given in Table 2. Also, the same study encountered a 10.65 kyr BP old sub-fossil moss *Pohlia nutans* preserved in the lake sediment at about 160-162 cm depth. The preserved Holocene sub-fossil moss includes delicate leaves, axes and rhizoids and matches perfectly the extant specimens of *P. nutans*.

Contributions to the Cyanobacteria and Algal Flora

Algae are most common biological elements in Antarctica exhibiting their presence in water bodies, wet soil, even on ice, in association with moss and lichens. About 700 algal taxa are known from the Antarctic continent and off-shore islands (Hirano 1965). Studies on the algal flora in Schirmacher Oasis was initiated by Richter (1995) who reported 209 taxa. There after several studies on algae (Fig. 1C,D) were under taken in the Oasis on both florist as well as ecophysiological aspects. However, studies on diatoms of the area ware meager and was carried out during 6th, 10th, 11th 18th, 23rd and 25th Indian Antarctic Expeditions. The study resulted in 18 diatoms belonging to 10 genera and five families. Of these *Diadesmis contenta, Fragellaria intermedia, Gomphonema lanceolatum, Navicula radiosa, Synedra ulna* and *Stauroneis anceps* are new records to Schirmacher Oasis (Kashyap *et al.*, 1988; Palanisamy 2007; Palanisamy 2010; Singh *et al.*, 2013). The check-list of diatom flora has been given in Table 3. The diatoms are found frequently associated with Cyanobacteria in the Oasis. The algae in Antarctica are also found growing in association with bryophytes as epiphytes to withstand the extreme climatic conditions. In one such studies 14 microalgae belonging to class Cyanophyceae, Bacillariophyceae and Chlorophyceae have been recorded growing in rhizodal zones of moss genera *Bryum* and *Pottia* (Singh *et al*., 2013). The other general studies on algae include Shukla *et al*. (1999) reporting 16 taxa and Singh (2000) reporting 33 taxa under Cyanophyceae, Chlorophyceae and Bacillariophyceae.

The Cyanobacteria (Fig. 1C) are oxyphototrophic prokaryote ubiquitous in all major ecosystems of the world including Antarctica. They are adapted to the Antarcitc environment in terms of temperature, freezing and thawing cycle, photoprotection, light acquisition or photosynthesis, low humidity and prolonged period of darkness. Earlier studies indicate that Cyanobacteria are most dominant component of flora in the regions of Antarctica that are ice-free (Broady 1982, 1989, Pandey *et al.*, 1992, 1995). The having ability to fix nitrogen Cyanobacteria are most important organism in Antarctica making soil suitable for the growth of other plants. Therefore, study of Cyanobacteria in Schirmacher Oasis and Larsemann Hills is very essential to understand the plant diversity in Antarctica and their response to changes in environmental condition and climate change. Kashyap *et al*. (1988, 1991) recorded 34 cyanobacterial taxa including unicellular, filamentous, non heterocystous and heterocystous forms in streams, lakes, associated with mosses and on soils of Schirmachar Oasis and reported *Stigonema minutum*, *Nostoc commune* and *Gloeocapsa* sp. as most common species. Pandey *et al.* (1995) studied the cyanobacterial flora of six fresh water streams of Schirmacher oasis and reported 30 species. Further, Singh and Elster (2007) reviewed cyanobacteria in Antarctic lake environment and highlighted their diversity, distribution and ecology. The diversity and distribution of cyanobacteria from the hydro-terrestrial and lake habitats of Schirmacher Oasis were mapped and a total of 109 species from 30 genera and 9 families were recorded (Singh *et al*., 2008). Recently, Pandey *et al*. (2013) enumerated a total of 35 Cyanobacteria from different habitats in Schirmacher Oasis and nearby nunataks. The check-list of cyanobacteria and green algal flora has been given in Table 4. In one of the studies it is found that nitrogen fixation by Cyanobacteria-moss association was highest in comparison to cyanobacteria found alone in soil near lake. However, Cyanobacteria were dominant flora (90%) of the soil surface in Schirmacher Oasis (Pandey *et al*., 2013).

Contributions to the Fungal Flora

The fungi are less hardy and more widely distributed organism in Antarctica in comparison to mosses and lichens. Their diversity increases with the availability of water and energy. They can withstand extremes of temperatures and severe desiccations. Yeast probably dominates and the majority of the microfungi reported from this place belong to cosmopolitan Hypomycetes (Singh *et al*., 2013). Six basidiomycetous yeasts were reported from Schirmacher oasis (Ray *et al*., 1989; Shivaji *et al*., 1994). The studies on the mycological flora of

Schirmacher Oasis were carried out during 17th Indian Antarctic Expedition onwards. Sharma (2000) reported nine species of fungi from the Schirmacher region. These include *Arthrobotrys ferox* on moss, *Torulopsis psychrophila* and *Phoma herbarum* on bird excreta, *P. herbarum* on skeletal remains, *Acremonium antarcticum* and *A. psychrophilum* on lichens and species of *Torulopsis psychrophila* and *Cryptococcus* on ornithogenic soils. Recently, Singh *et al*. (2013) enumerated a total of 19 species of fungi belonging to 13 genera under seven families from Schirmacher Oasis. The check-list of fungal flora has been given in Table 5. Except for *Dacrymyces* and *Exidia* all the species were recorded for the first time from Schirmacher Oasis. Melt water streams originating from glacier supported the luxuriant growth of lichens and moss cushions which served as potential source for fungal isolation.

In subsequent years, biodiversity of psychrophilic fungi (*Acremonium*, *Aspergillus*, *Cladosporium*, *Fusarium* and *Trichoderma*) from Schirmacher Oasis (Singh *et al*., 2006) and 5 species of yeasts (*Cryptococcus albidus*, *C. antarcticus, Mrakia blollopis Rhodotorula microsporus*, *Thelebolus microspores*) from Larsemann Hills were also assessed (Singh *et al*., unpublished). A cold-tolerant fungal strain *Thelebolus microsporus* was investigated for the first time for its pigment and fatty acid production from Larsemann Hills (Singh *et al*., 2014). Recently, an exopolysaccharide (EPS) was isolated, purified and characterized which is the first ever report on bioactive EPS thelebolan from *Thelebolus* sp. (Fig. 1E-F) (Mukhopadhyaya *et al*., 2014).

Conclusion

Though Schirmacher Oasis and Larsemann Hills among the most extensive ice-free areas of continental Antarctica, yet, knowledge of the terrestrial biology of these areas are still fragmentary and needs detailed investigations in year to come. While much of the contribution on the diversity and distribution of algae, fungi, lichens and bryophytes is available for Schirmacher Oasis not much information is available for Larsemann Hills on these aspects. Therefore, there is tremendous scope for conducting biological diversity study in this area. However, documentation of biodiversity and understanding the basis of their adaptation to harsh conditions of Antarctica have become routine activities, but now the time has come to translate our basic knowledge into bioprospection for the benefit of mankind. Antarctic biodiversity may serve as potential genetic resources for life saving drugs or to protect our skin from harmful ultra-voilet rays or cultivate economically important plants and animals in cold conditions. Isolation of antifreeze glycoproteins from various species of Antarctic fish is a best example in this respect where scientists are looking for ways to improve farm-fish production in cold climates, extend the shelf life of frozen food and enhance the preservation of tissues to be transplanted. The bioprospecting activities in Antarctica are increasing and several patents are already been filed based on biodiversity of Antarctica. During the year 1988-2003 of the 18 companies that have applied for Antarctic based patents, most applicants are Japanese-based companies, followed by German ones (Lohan and Johnston 2005). At present prospecting Antarctic bioresources for commercial application has restricted due to existence of Antarctic Treaty System. However, ambiguity in Antarctic Treaty such as ownership of genetic resources, legitimate access to bioresources, benefit sharing, environmental impact assessment etc. need to be readdressed so that novel genetic wealth of Antarctica can be used for betterment of human life.

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