Antarctic Lichen Response to Climate Change: Evidence from Natural Gradients and Temperature Enchantment Experiments

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Abstract Antarctica is one of the very few ecosystems in the world with minimum anthropogenic interventions and pollution load. The extreme climatic conditions such as temperature, precipitation, and smaller ice-free regions allow only cryptogams such as bryophytes and lichens to grow dominantly. Although lichens are well-known biomonitors and bioindicators of climate change, environmental pollution and anthropogenic perturbations, their potential has been explored very recently. In this chapter, various climate-change studies in Antarctica employing lichens as an integrated bioindicator system are reviewed. The studies utilized either natural gradients of climate across the continent or passive or active air temperature enhancement experiments. The lichen communities in Antarctica has been found sensitive to both climatic clines and temperature manipulations. The lichens' response was species-specific, the species with wider distribution were more adaptive to climate change than those with restricted distribution. The studies also indicated that climate warming would cause the extinction of sensitive species. Simultaneously, some will increase their geographical extension due to the increased water availability and nutrients in changed ecosystems.

Keywords Cryptogam · Lichenized-fungi · Ecophysiology · Global warming · Biodiversity loss · Bioindicator

1 Introduction

Earth's environment has been unusually stable for the past 10,000 years. Anthropogenic actions since the industrial revolution have become the primary driver of global environmental change. Climate change, biodiversity loss, nitrogen and phosphorus cycles have crossed the critical levels of the threshold for the sustenance of humanity on earth (Rockström et al. 2009). The mitigation of these factors primarily requires their early detection and thorough understanding of each component (Cash

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et al. 2003). Traditionally, climate change monitoring involves satellite data, ground studies, and modelling of the predications (Appenzeller et al. 2008). The higher maintenance cost of the traditional climate change monitoring systems and the inconsistency of monitoring data to actual events have necessitated the researchers to utilize bioindicators such as fish, insects, mussels, lichens, algae, plants and birds (Guralnick 2002; Caza et al. 2016).

Amid the various bioindicators, lichens, the symbiotic association of a fungus and green or blue-green algae (sometimes both) has been utilized to monitor air pollution as early as 1866 (Nylander 1866). Apart from being excellent accumulators of pollutants (heavy metals, aromatic hydrocarbons and nitrogen), lichens also indicate land-use change and various other anthropogenic activities world-wide (Garty 2001; Wolterbeek et al. 2003; Blasco et al. 2008; Rai et al. 2012; Loppi 2019; Landis et al. 2019; Nascimbene et al. 2019; Serrano et al. 2019; Zhao et al. 2019; Capozzi et al. 2020; Wang et al. 2020). Lichens are also a proven indicator of climate change (Sancho et al. 2007; Ellis 2019). Unlike pollution monitoring studies, climate change studies are influenced by other ecological factors, such as phorophyte types, forest structure and pollution loads. Therefore, climate changes studies employing experimental, and modelling systems must incorporate different aspects of the environment (Ellis et al. 2007; Aptroot 2009; Nascimbene et al. 2016; Alatalo et al., 2017; Ellis 2019; Giordani et al. 2019). In Antarctica these interfering factors are minimized, especially in lichen-based climate changes studies as the continent has minimal air pollution (Upreti and Pandey 1994; Mietelski et al. 2000; Bargagli et al., 2004) and anthropogenic influence but has diverse lichen communities and environmental gradients (Øvstedal and Smith 2001).

Situated in the southern hemisphere, Antarctica is the fifth-largest continent with an area of 14,200,000 km^2. The average elevation of Antarctica is 2500 m, the highest for any continent. The ice sheet covers about 98% of the continent with about 1.9 km of average thickness (Fretwell et al. 2013). The low-elevational areas are either in proximity to the seacoast or at the coast. The ice-free area includes only 0.18% (21,745 km^2), the majority of which lies in the Antarctic peninsula, Trans-Atlantic mountains, along with Dronning Maud land, various coastal islands and nunataks (Rai et al. 2011; Burton-Johnson et al. 2016). Antarctica is the coldest continent with an average minimum temperature ranging from −63 °C in coastal areas to −89.2 °C in continental Antarctica. It is a cold desert with an annual precipitation maximum of up to 200 mm in the coastal habitats and much lesser in continental Antarctica. Two biogeographic zones can be recognized within the continent—the continental and maritime Antarctica (Smith 1984; Convey 2001), which are further categorized into sixteen eco-regions (Terauds and Lee 2016) (Fig. 1). Antarctica vegetation is primarily dominated by cryptogams, i.e. bryophytes and lichens, except for two vascular plants *Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth) Bartl. are limited to the peninsular region (Smith 1994; Convey 2006).

The lichen community of Antarctica is represented by 427–500 species accounting for about 2.5% of the total estimated lichens globally (i.e. ~20,000 species, Lücking et al. 2016), of which 40% are endemic to the continent (Smith and Øvstedal 1991; Upreti and Pant 1995; Upreti 1996, 1997; Gupta et al. 1999; Pandey and Upreti 2000;

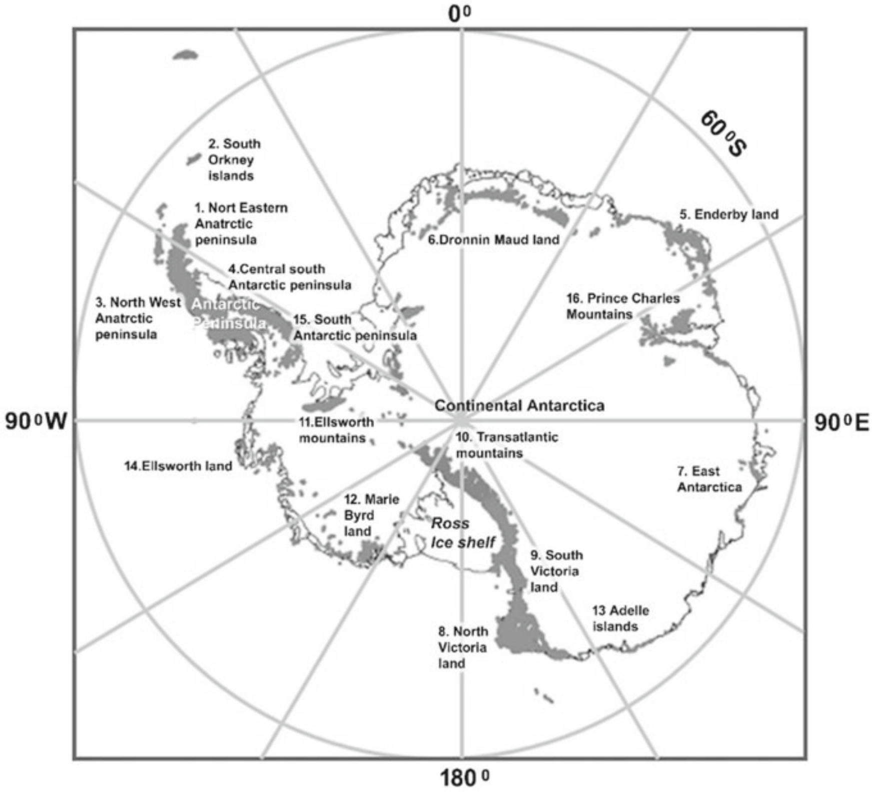

Fig. 1 The two biogeographic zones and sixteen eco-regions of Antarctica (after Smith 1984; Convey 2001; Terauds and Lee 2016)

Øvstedal and Smith 2001; Sancho et al. 2004; Krzewicka and Smykla 2004; Nayaka and Upreti 2005; Kim et al. 2006; Singh et al. 2007; Krzewicka and Maciejowski 2008; Olech and Czarnota 2009; Osyczka et al. 2010; Ruprecht et al. 2010; Upreti and Nayaka 2011; Green et al. 2015; Park et al. 2018). The lichens with cyanobacteria as primary (i.e. bi-partite) or secondary photobionts (i.e. tripartite) are specifically restricted to the wetter and warmer peninsular region (Green et al. 2011a, b). The green algae containing chlorolichens are distributed throughout the Antarctic with the dominance of crustose forms and few endemic fruticose species (e.g. *Usnea Antarctica* Du Rietz) (Green et al. 2011a, b). Lichens play a crucial role in the ecosystem functioning of the Antarctic. They are the pioneer colonizer on denuded surfaces which initiate ecological succession and soil formation (Walton 1985; Ascaso et al. 1990; Sancho and Valladares 1993). Lichen also contributes to nutrient cycling and a food source to the invertebrates in the Antarctic habitats (Lindsay 1978; Greenfield 2004; Kennedy 2004; Cannone et al. 2006; Bokhorst et al. 2007a, b; Leishman et al. 2020).

Antarctic lichen research was initially focused on the taxonomy and floristics from the peninsular and accessible regions of the continent (Øvstedal and Smith 2001; Krzewicka and Maciejowski 2008; Park et al. 2018). Studies then gradually focused on ecophysiology and generating baseline data for environmental gradients (i.e. climatic and species). In situ, in vitro temperature and nutrient manipulation experiments were carried to understand the effects of a warming climate in contracting habitats and climatic conditions (Lange and Kappen1972; Barták et al. 2003; Schroeter et al. 2011; Nayaka et al. 2011; Balarinová et al. 2014; Laguna-Defior et al. 2016; Raggio et al. 2016; Cho et al. 2020). Due to the harsh environmental conditions in continental Antarctica, limitations associated with movement, transportation and unforeseen situations, the climate change studies employing lichens as response organisms are primarily reported from the peninsular region and maritime islands (Table 1). The lichen-based climate change studies can broadly categorize into two types (i) studies utilizing the natural gradients of climate and lichen communities as a proxy to climate change, (ii) manipulating the ambient air temperature using either passive and/or active experimental setups to imitate the warming conditions (Table 1).

2 Gradient Studies

The analysis of lichen response along climatic, species, growth form and time series gradients are some of the most appropriate methods to accurately monitor and predict the climate change in stressed habitats of Antarctica (Huiskes et al. 2004; Anderson et al. 2012; Rodriguez et al. 2018; Folgar-Cameán and Barták 2019). The gradients forces species to change their adaptability to optimize their physiology, ecological distribution and reproductive strategies (Chen et al. 2011; Tomiolo and Ward 2018; Determeyer-Wiedmann et al. 2019; Pérez-Ramos et al. 2020; Rolshausen et al. 2020). In Antarctica, the environmental gradient effect is more pronounced on the lichen communities due to minimum interference from the phytosociological competition and other abiotic factors such as pollution.

The growth of lichen thallus is one of the most reliable parameters for studying the response of lichens to microclimatic (e.g. water availability and nutrient deposition) as well as macroclimatic (e.g. temperature and precipitation) variables (Kershaw 1985). Sancho and Pintado (2004) studied the growth rates of six lichens *Acarospora macrocyclos* Vain., *Bellemerea* sp. *Buellia latemarginata* Darb., *Caloplaca sublobulata* (Nyl.) Zahlbr., *Rhizocarpon geographicum* (L.) DC. and *Usnea antarctica* in Livingston Island, South Shetland Islands, maritime Antarctica. The study compared the growth rates of the lichens between 1991 and 2002. All the studied lichens showed a higher increased growth rate ever reported for crustose lichens of the region. In contrast, two lichens, *R. geographicum* and *Bellemerea* sp. showed significantly higher growth rates. Such a tendency was attributed to the Livingston Island ice cap and glaciers' rapid retreat during that decade, which was speculated to global warming (Sancho and Pintado 2004). Sancho et al.

Table 1 Climate change studies carried out in Antarctica using various natural gradients and temperature enhancement experiment

S. No	Study type	Experimental setup used	Lichen species/communities used	Location of study	Major findings	References
1	Natural gradient	Species growth rate gradient	*Acarospora macrocyclos, Bellemerea* sp., *Buellia latemarginata, Caloplaca sublobulata, Rhizocarpon geographicum, Usnea antarctica*	Livingston Island, Maritime Antarctica	Higher growth rate due to global warming	Sancho and Pintado (2004)
2	Natural gradient	Climate gradient	*Buellia latemarginata, Buellia frigida*	Western Antarctic Peninsula and Dry Valleys, near Ross Island	The growth rate difference following climatic gradient	Sancho et al. (2007)
3	Natural gradient	Latitude linked climatic gradient	Lichen communities	Peninsular and continental sites	Two separate zones were identified based on the influence of macroclimatic and microclimatic factors influencing the lichen communities	Green et al. (2011a, b)
4	Natural gradient	Latitude linked microclimatic climatic gradient	Lichen communities	Sites along the western Ross sea coast	Lichen communities were influenced by microclimatic conditions, e.g., availability of water	Colesie et al. (2014)

(continued)

Table 1 (continued)

S. No	Study type	Experimental setup used	Lichen species/communities used	Location of study	Major findings	References
5	Natural gradient	The long-term atmospheric temperature gradient	*Bellemerea* sp., *Buellia latemarginata*, *Caloplaca sublobulata*, *Rhizocarpon geographicum*, *Acarospora macrocyclos* and *Usnea antarctica*	Livingston Island, Maritime Antarctica	Species-specific response corresponding to temperature variations. “Snow kill” affects negatively on the growth of some crustose lichens	Sancho et al. (2017)
6	PTES	Temperature enhancement using OTCs, comparative assessment	Lichen communities	Livingstone Island, Maritime Antarctica, Falkland island, sub-Antarctic	Open plant communities (lichens and mosses) are negatively affected by warming	Bokhorst et al. (2007a, b)
7	PTES	Temperature enhancement using OTCs	*Usnea antarctica*	Signy Island, maritime Antarctic	Temperature stress negatively affect the lichen growth	Bokhorst et al. (2016)
8	PTES	Temperature enhancement using OTCs	*Placopsis antarctica*	Fildes Peninsula, maritime Antarctica	Temperature decreases the photosynthetic efficiency of lichens	Casanova-Katny et al. (2019)
9	Field manipulations	Water and nutrient addition as a proxy to global warming	*Usnea* sp.	Windmill Islands in East continental Antarctica	Water and nutrient availability influences lichens growth	Wasley et al. (2006)
10	ATES	Growth chamber temperature enhancement	*Stereocaulon alpinum*, *Placopsis contortuplicata*, *Usnea aurantiaco-atra*	Livingston Island, maritime Antarctica	Antarctic lichens can’t tolerate the temperature increase	Colesie et al. (2018)

(continued)

Table 1 (continued)

S. No	Study type	Experimental setup used	Lichen species/communities used	Location of study	Major findings	References
11	Natural gradient, PTES and ATES	Temperature enhancement using polystyrene glasshouse, geothermal heat, laboratory incubation	Lichen communities	Islands in maritime Antarctica	Temperature increases the lichen cover and diversification	Kennedy (1996)

(2007) estimated the growth rates of two taxonomically related crustose lichen species *Buellia latemarginata* and *Buellia frigida* Darb., from sites located in maritime Antarctica and continental Antarctica, respectively, for nine to 25 years. *B. latemarginata* (87 mm 100 y^{-1}) recorded the fastest growth rates ever recorded from Antarctica, whereas *B. frigida* recorded minimal, barely detectable growth (1 mm 100 y^{-1}). The extreme difference in growth rate was attributed to temperature linked precipitation at two habitats. The study concluded that extreme cline in the Antarctic lichen species' growth rate could be used to indicate climate change-induced temperature variation when the growth rate is recorded at a specified time interval for long period monitoring (Sancho et al. 2007).

Sancho et al. (2017) monitored the effect of regional temperature variations on the growth of six lichen species (*Acarospora macrocyclos, Bellemerea* sp., *Buellia latemarginata*, *Caloplaca sublobulata*, *Rhizocarpon geographicum* and *Usnea antarctica*) in Livingston Island, South Shetland Islands, maritime Antarctica for 24 years. The regional mean summer temperature (MST) of the study location between 1991 and 2002 increased to 0.42 °C, whereas a decline of 0.58 °C was observed from 2002 to 2015. The temperature fluctuation response on the lichens' growth was species-specific, where some species (*Buellia latemarginatai*) showed no reaction. In contrast, some species (*Bellemerea* sp., *Rhizocarpon geographicum* and *Usnea antarctica*) responded positively with an increase in growth rate from 1991 to 2002 followed by a decrease accordingly to MST in 2015. The lichen species *Caloplaca sublobulata* and *Acarospora macrocyclos* reacted differently with a reduction and increase respectively, from 1991 to 2002, followed by an abrupt decline in thallus growth from 2002 to 2015. Such response was attributed to the thallus' snow kill due to the longer spans of snow cover (Sancho et al. 2017). Among the six species, *Usnea antarctica,* due to its robust upright fruticose thallus and water utilization capacities, emerged as an appropriate proxy of Antarctica's temperature variations (Sancho et al. 2017). Here, the "snow kill" represents a threshold of lower temperature in Antarctica, which can be a driver for the extinction of specific lichen communities and extension for others (Sancho et al. 2017). The studies revealed that Antarctic lichens' growth indeed responds to climate warming, where the pioneer colonizer utilizes the resources made available by retreating glaciers. The steep difference in temperature of maritime and continental Antarctica affects lichen growth through precipitation variability. The long-term temperature variation affects the lichen growth according to the increase and decreases and physical damage caused by a more extended snow deposition period.

Antarctica's latitudinal gradient influences the solar insolation on the continent, which affects the climate creating a cline that can act as a proxy to climate change or global warming conditions. Green et al. (2011a, b) studied Antarctica's terrestrial vegetation as a predictor of climate change, considering the latitudinal incline and associated climatic variation as proxies. The study involved regression analysis of the number of lichen species on latitude and meant annual temperature gradient. The study determined two zones of terrestrial lichen vegetation—the micro-environmental and macro-environmental zone. The micro-environmental area lay south of 72° S. The vegetation is predominately influenced by the microclimatic parameters such as the occasional occurrence of warm ambient environmental temperature, water availability, sunlight, and shelter. Further in this zone, the lichen physiology is essentially modulated to survival mode by curtailing the thallus growth (Green et al. 2011a, b). The macro-environmental area, which lays north of 72° S in maritime Antarctica, is characterized by lichen species richness, higher cover and growth. Due to the increase in water availability, moderate atmospheric temperature, and longer active periods, the macro-environmental zone allows great net productivity switching lichen vegetation from surviving mode to growth mode (Green et al. 2011a, b). Cyanolichens incapable of performing physiological activities in sub-zero temperatures were found distributed to maritime Antarctica but with only four species, i.e. *Leptogium puberulum* Hue, *Massalongia* aff. *carnosa* (Dicks.) Körb., *Pannaria hookeri* (Borrer) Nyl. and *Pyrenopsis* sp. These species were distributed on the main continent in proximity to the maritime Antarctic Peninsula. The study further concluded that temperature increase due to global warming would have some predictable effects, such as—the lichen diversity will increase in the macro-environment zone, and there will be a southward extension of this zone. There will be a significant change in the micro-climatic zone's species composition as a local microclimate guide. The cyanolichens will fan out in the coastal habitats limited by the availability of appropriate substratum. The study further highlights Antarctica's unique latitudinal cline, which can be imitated to predict the present and future lichen community diversity and changes triggered by global or regional warming.

Continental Antarctica is characterized by a harsher climatic regime where the microclimatic resources such as water availability are limited due to occasional thawing events that decide lichen species composition and community structure. Colesie et al. (2014) studied variations in lichen communities in six sites (Cape Hallett, Terra Nova Bay, Botany Bay, Taylor Hill, Diamond Hill, and Queen Maud mountains) latitudinal gradient at the western Ross Sea coastline in north Antarctica. The study found a decrease in lichen diversity from Cape Hallett to Diamond Hill except Queen Maud mountains, which harbours similar lichen diversity as Cape Hallett. The study concluded that lichen diversity was potentially guided by microclimatic conditions (i.e. water availability) rather than macroclimatic parameters in continental Antarctica.

The long-term studies in Antarctica on the effect of climate on the lichen communities and their dynamics have also exposed the direct impact of climate warming and the glacial retreat. Olech and Słaby (2016) studied the change in lichen communities 1988–1990 and 2007–2008 in King George Island, maritime Antarctica, to the regional climate change. The comparative study recorded significant differences, especially in the glacial forcefield recently exposed due to glacier retreat (White Eagle Glacier between 1988 and 2008) due to global warming. The study reported the extinction of some species (*Polyblastia gothica* Th. Fr., *Thelenella kerguelena* (Nyl.) H. Mayrhofer, *Thelocarpon cyaneum* Olech & Alstrup), reduction in the distribution of species (*Leptogium puberulum*, *Staurothele gelida* (Hook. f. & Taylor) I. M. Lamb and increase in extant of pioneering species (*Bacidia chrysocolla* Olech, Czarnota & Llop, *Caloplaca johnstonii* (C.W. Dodge) Søchting & Olech, *Candelariella aurella* (Hoffm.) Zahlbr., *Lecanora dispersa* (Pers.) Röhl.). The study emphasized the lichen communities' change in the glacial moraine forefield exposed due to glaciers' retreat due to climate warming during the last 5–6 decades. The study points towards the biodiversity loss in the form of lichen species extinction and proliferation of early successional lichens, both triggered by the significant glacial retreat in the past 50 years. Thus, Olech and Słaby (2016) study provide a strong reason for including lichens in Antarctica climate change studies.

3 Experimental Manipulation Studies

The experimental temperature enhancement has been used extensively to study the effect of global warming in the past two decades (Marion et al. 1997). Manipulative warming or temperature enhancement can be achieved by two methods, (i) Passive temperature enhancement systems (PTES) using open-top chambers (OTC). Here, the study surface temperature is enhanced in situ by concentrating and retaining solar insolation for a more extended period diurnally and seasonally (Rai et al. 2010). The PTES have continuity of experimental microenvironment with the ambient natural environment. (ii) Active temperature enhancement systems (ATES) using closed experimental equipment such as growth chambers or incubator. Here the predetermined temperature is enhanced along with manipulating light–dark hours, relative humidity operating heating assemblies and fluorescence lights.

PTES using OTC have been successfully used to elevate the temperature triggering the warming effect on the ground lichens (Barták et al. 2019). Bokhorst et al. (2007a, b) studied the effect of experimental warming using OTC on the cryptogam communities (i.e. lichen and bryophytes) of coastal ecosystems in two Maritime islands (i.e. Signy Island and Anchorage Island) and one sub-Antarctic Island (i.e. Falkland Island) for three summers. The study recorded a significant decrease in the moss vegetation cover in Falkland Island and lichens in Signy and Anchorage Island. The results were linked to drought stress induced by the elevated temperatures within the OTCs. The study concluded that the open plant communities (lichens and mosses) are compassionate to even the slightest change in the climatic variables in the sub-Antarctic to Antarctic habitats (Bokhorst et al. 2007a, b). Bokhorst et al. (2016) studied the effect of simulated warming using OTCs on the cover of the dominant lichen *Usnea antarctica* in Signy Island (northern maritime Antarctic) for 10 years (2003–2013). They recorded about 71% loss in the lichen cover. The study concluded that the lichen cover decrease was due to lichen's inability to compensate for the increased carbon loss in summer. The higher net respiration rate was driven by the elevated ambient temperature in the OTCs.

Casanova-Katny et al. (2019) studied climate change on a tripartite cyanolichen *Placopsis antarctica* D.J. Galloway using OTCs, which enhanced the ambient atmospheric temperature up to 2.2 °C than the control sites at Fildes Peninsula, King George Island (maritime Antarctica). The effective quantum yield of photosystem

II (Φ_{PSII}), photosynthetic electron transport rate (ETR), photosynthetically active radiation (PAR) and hydration state of the thallus at 10 min interval were measured for 12 days (Fig. 2). The study concluded that elevated temperature within OTCs and dehydration of the thallus limit the photosynthetic processes in *P. antarctica.* That was further reflected in decreased ETR and chlorophyll fluorescence of samples. The effects of manipulated warming were also confirmed by laboratory hydration experiments where the chlorophyll fluorescence (FM) and Φ_{PSII} corroborated the field studies. The photosynthetic parameters reacted according to the hydration level of the thallus (Fig. 3). OTCs study reflected the physiological stress lichens will encounter global warming, which can be used as an early indicator for long-term studies and further understand the lichen physiology under high-temperature conditions.

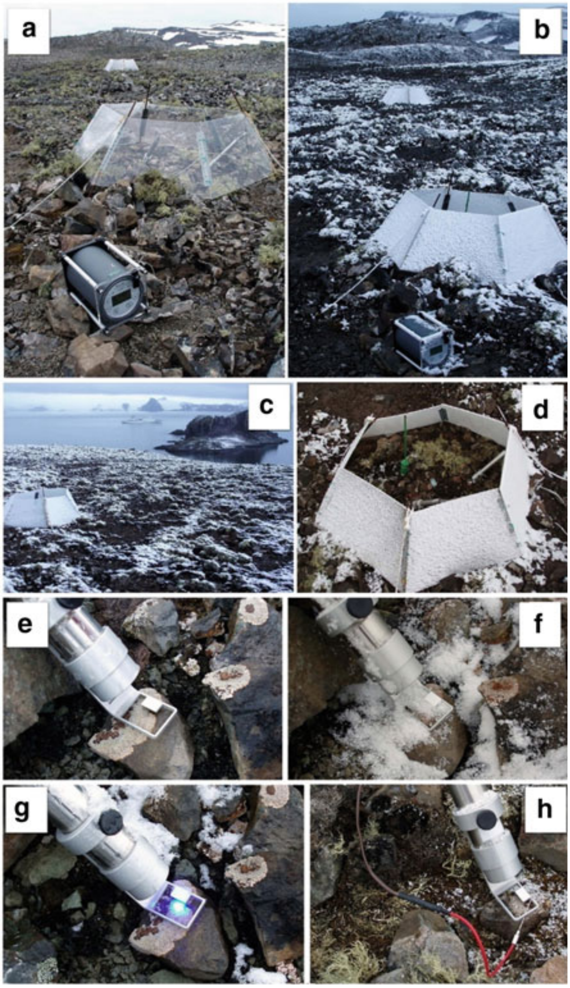

Fig. 2 Experimental set up of the MONI-PAM with measuring probes installed over *Placopsis antarctica* thalli. **A** An overview of the OTCs located on La Cruz Plateau; **B**–**D** The OTC after snowfall (Note the absence of snow in the OTC in D due to elevated temperature), **E**–**F** The measuring probe on the control plot (E- after a rainfall, F- after a snowfall), **G** The saturation pulse spot on *Placosis antarctica* thallus, H. The measuring probe and Cu-Co thermocouple measuring air temperature at the measuring location inside OTC (Photographs © M. Barták, after Casanova-Katny et al. 2019)

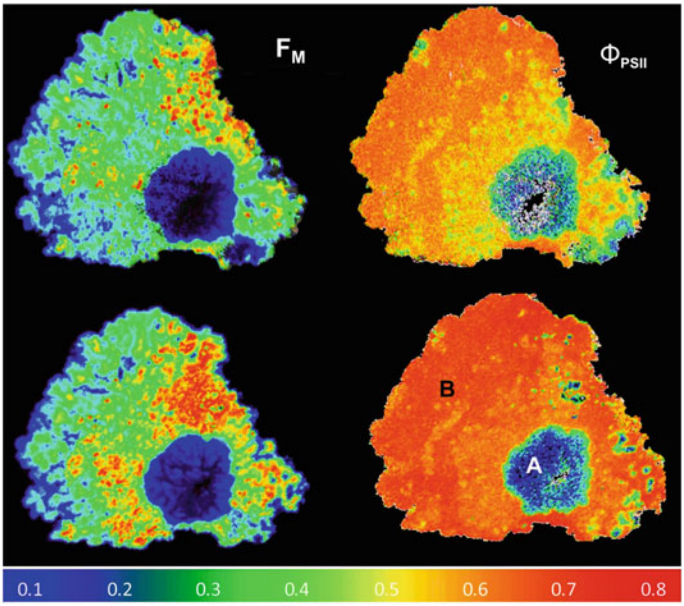

Fig. 3 Chlorophyll fluorescence imaging of *Placosis antarctica* thallus hydrated for 1 h (upper panels) and 48 h (lower panels). Φ PSII—effective quantum yield of photosystem II, A-Cephalodium possesses *Nostoc* commune, B—marginal part of the thallus possessing green microalga (after Casanova-Katny et al. 2019)

The ground lichen vegetation can be manipulated with water and nutrients as a proxy to climatic warming. Wasley et al. (2006) studied the effect of increased water and nutrient availability on lichen (*Usnea*) and bryophyte communities in the Windmill Islands in East Antarctica. The primary productivity (chlorophyll content, fluorescence, and nutrient content) was used indicator. The study concluded that though water availability plays a vital role in developing and maintaining lichen communities, the nutrients act as a determinative factor (Wasley et al. 2006).

ATES using growth chambers or incubators has been rarely used to study the effect of simulated warming but can successfully demonstrate some species-specific results and insight into the species reaction to climate change. Colesie et al. (2018) studied the effect of temperature elevation on three lichens (*Placopsis contortuplicata* I. M. Lamb, *Stereocaulon alpinum* Laurer*, Usnea aurantiaco-atra* (Jacq.) Bory) collected from Livingston Island in peninsular maritime Antarctica using a growth chamber. The activated lichen samples were subjected to temperature gradients of 5° (control), 15° and 23 °C, and hydration-desiccation cycles (3–4 days) for six weeks (apparently to mimic the natural conditions). The respiration, net photosynthesis, and chlorophyll fluorescence of the samples were analyzed. The study found that 15 °C was the upper limit of temperature for photobionts viability in *P. contortuplicata* and *U. aurantiaco-atra* whereas widely distributed *S. alpinum* was able to retain its photosynthetic vitality. The study indicated species-specific response to lichens growing in Antarctica where specialized species (*P. contortuplicata* and *U. aurantiaco-atra*) mostly restricted to the continent negatively affected climate warming widely distributed species which have wide acclimatization range to temperature variability. The study highlights Antarctic lichen's extreme sensitivity, which is incapable of coping with extreme atmospheric temperature fluctuation induced by climate change.

Studies employing PTES, ATES and natural gradients decipher the intricate correlation of lichen response to the wild and experimental setups. Kennedy (1996), by analyzing the proxies of climate warming such as passive polystyrene glasshouses, geothermal heated ground and laboratory incubation of soil samples from maritime Antarctica (i.e. Signy island, Candlemas island, Deception island), concluded that climate or substratum warming increases the lichen cover and supports initiation and diversification of lichens in the otherwise harsh climate of Antarctic. The study indicated the more significant expansion of cryptogamic communities is limited by physiological constraints under global warming in Antarctica.

4 Discussion and Conclusions

Antarctica offers several advantages for climate change studies using lichens as integrative bioindicators due to its unique global ecology positioning. The minimal human interference, lowest pollution levels, dominant ground vegetation of lichens with minimal to no vegetative competition, a wide range of climatic with gradients of temperature and precipitation are some of these advantages. However, studies carried out so far are scarce in comparison to other habitats of the planet. The lichen communities of Antarctica show diverse behaviour in the pattern of distribution and physiology as an indicator to natural climatic gradients and experimental warming, which can be summarised as follows

1. The lichen communities in maritime Antarctica show high diversity due to milder temperature regime and high precipitation, which tend to extend southwards with climate warming.
2. The cyanolichens are limited to maritime Antarctica and peninsular regions. Climate change-induced warming will increase their extension deep into the continental area with limitations of physiological parameters.
3. Climate change-induced warming will increase the pace of glacier retreat, increasing the current extent of lichen communities in all the habitats of Antarctica.
4. The increased temperature will tend to alter the net photosynthesis of lichens. It will have a detrimental effect on the endemic species as they are less adaptive than lichens having circumpolar distribution. This will lead to the extinction of some species during extension and invasion of other species.

The studies carried out so far on Antarctica's lichens indicate that climate change is harmful, leading to biodiversity loss.

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