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RESEARCH LETTER

Lichens of Laguna San Rafael, Parque Nacional 'Laguna San Rafael', southern Chile: indicators of environmental change

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Abstract. A synopsis of lichens collected in 1990 from Laguna San Rafael, Parque Nacional 'Laguna San Rafael', southern Chile, is presented, together with information on habitats where they are important components of the vegetation. Lichens are suggested as potential indicators of both short-term and longer term environmental changes in the area, and their biogeographical and ecological importance is briefly discussed.

Key words. Lichens, bioindicators, glaciation, temperate rain forest, Chile.

INTRODUCTION

The vegetation of southern South America has held a fascination for botanists since the eighteenth century when European navigators first opened the Pacific Ocean to geographic and scientific discovery. Entry to the great unknown of the Pacific lay either through the dangerous narrows of the Straits of Magellan, or around Cape Horn, both passages prey to violent storms and contrary winds. However, in this desolate region there were treasures awaiting the intrepid botanist (Moore, 1983). Although lichens were first collected from Tierra del Fuego in *c.* 1690 by George Handisyd, surgeon of the East Indiaman, *Modena*, it was not until the end of eighteenth century when the great European voyages of geographical and biological discovery sailed into the largely uncharted Pacific that lichens from southern latitudes were seriously collected, described, illustrated and circulated in herbaria (Galloway, 1985, 1992). The first lichen to be described from the Southern Hemisphere was *Pseudocyphellaria berberina* (G. Forster) D. Galloway & P. James, collected by George Forster in 1774 from Christmas Sound, Tierra del Fuego during Captain Cook's second great circumnavigation (Galloway & James, 1977). Tierra del Fuego was the locality for many late eighteenth and early nineteenth century lichen collections, and although the rollcall of botanists was impressive: Commerson, Banks and Solander, Menzies, Gaudichaud-Beaupré, Durville, Darwin, and Joseph Hooker, very little appeared in print about South American lichens until towards the middle of the nineteenth century when the early accounts of Chile's lichens were published (Galloway, 1985, 1991a). These covered mainly the rich lichen vegetation of the Valdivian rain forest, and the lichen flora of Tierra del Fuego, in many ways two strikingly distinct floras.

Of the region between Valdivia and the far south very little was known botanically and certainly no lichens were collected, although the *Beagle* anchored for several days at Punta Tres Montes, and Charles Darwin was impressed enough with the rich growth of lichens in the lowland forests of islands in the Chonos Archipelago to make fine collections of them in December 1834, from which derives the type of *Sticta divulsa* Taylor [= *Pseudocyphellaria divulsa* (Taylor) Imshaug].

Raleigh International have a continuing interest in scientific exploration of the Taitao Peninsula and the nearby Laguna San Rafael area using Venturer support (Cook, 1991). An objective of Field Project 90A (Trapananda Expedition), to Laguna San Rafael and the Taitao Peninsula in January–February 1990, was to collect data on lichens in the region from all of the

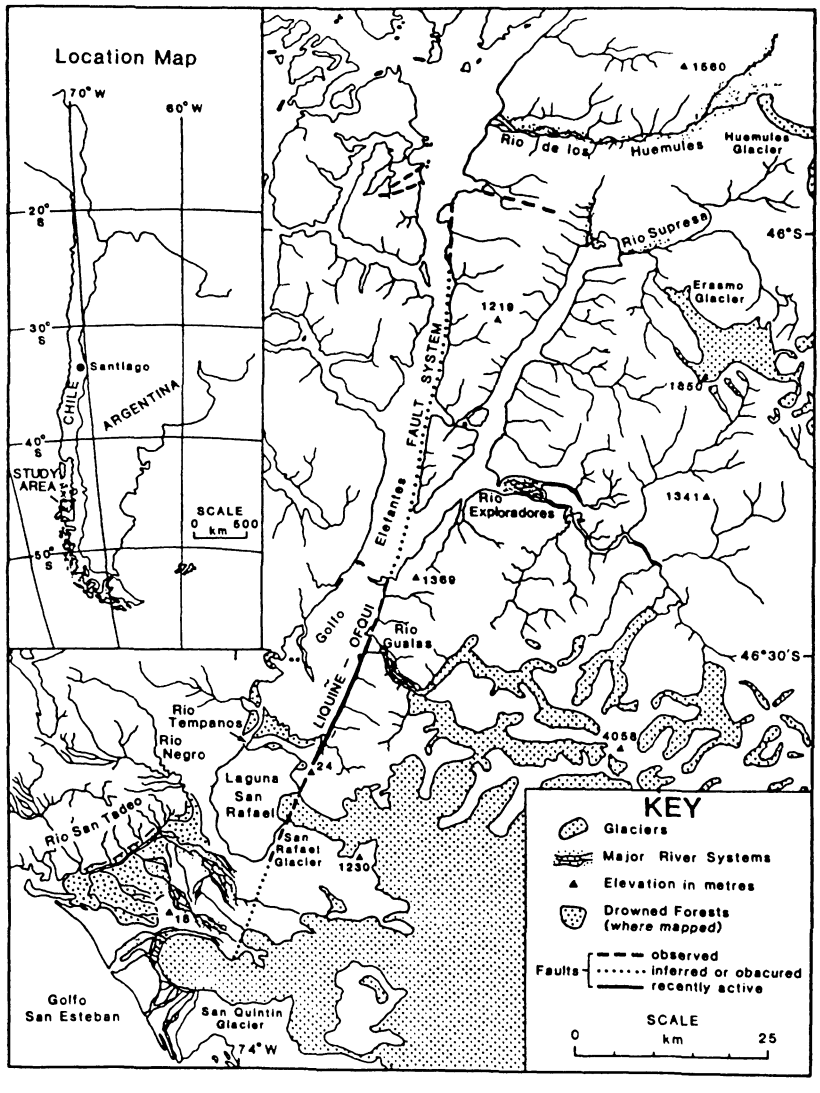

Fig. 1. Map showing the study area around Laguna de San Rafael, Chile. (After Reed, Wood & Best, 1988.)

main habitats, and to compare this data with known records of Valdivian rain forest lichen vegetation to the north, and from Tierra del Fuego to the south. Because of logistic difficulties, sampling of lichen vegetation was restricted to the environs of Laguna San Rafael, where a comprehensive collection of lichens was made, with Venturers, between 26 January and 16 February 1990. Our base was a camp-site at Las Paraguas, midway between the abandoned hotel and the snout of the San Rafael Glacier.

GEOGRAPHICAL SETTING

Laguna de San Rafael is located in Chile's XI Region in Aisén Province at about 46°40'S: 74°00'W, at the foot of the Andean cordillera some 160 km SSW of Puerto Chacabuco and 570 km S of Puerto Montt (Fig. 1). It is one of the more accessible parts of the vast and remote Parque Nacional 'Laguna San Rafael'. The laguna occupies the southern end of a continuous waterway starting at Puerto Montt and

which includes the Golfo de Ancud, Golfo Corcovado, Canal de Moraleda, Canal Costa, Estero Elefantes and Golfo Elefantes. The Istmo de Ofqui, some 20 km wide, separates the laguna from the Golfo de Peñas to the south-west which opens onto the Pacific Ocean. The laguna is reinform in outline and measures 16 km from north to south and 11 km from east to west. Low cliffs of unconsolidated glacial drift, no more than 15 m high, form much of the laguna's rim. Two ancient moraines, named Tempanos I and II, make up the rim. The remains of a third moraine, Tempanos III, are seen as several small islands and a peninsula along the northern shore (Heusser, 1960, 1964). Low, relatively-open ground consisting of modern moraines and outwash, border the laguna to the north-east.

The San Rafael Glacier is the dominating feature of the area and calves into the laguna on its eastern side having descended from the North Patagonian Icecap (Hielo Patagonico norte) and the slopes of Cerro San Valentin (4058 m), the highest summit in the southern Andes. From 1945 until 1983, the front of the glacier retreated some 2600 m (Aniya & Enomoto, 1986), and it is still retreating rapidly, exposing fresh rock surfaces to active lichen colonization.

Climate in the area is typically oceanic, cool and moist, a consequence of the Laguna's position at the foot of the cordillera and in the path of cyclonic storms which move in from the Pacific Ocean. The profusion and biomass of epiphytic and terricolous lichens attest to high rainfall and cloudy conditions, ideal for rapid lichen growth. However, between 26 January and 16 February 1990, while we were based in the area, we experienced rain on only 8 of the 22 days.

The environment of Laguna San Rafael, with references to earlier literature on the area, is discussed by Heusser (1960, 1964), geology and tectonic features by Reed, Wood & Best (1988) and Wood (1989), and the vegetation and vascular flora by Pisano (1988).

Prior to the present investigation, lichen collections from the area seem to be only two in number. A collection made from the Istmo de Ofqui in January–February 1921 by C.M. Hicken and preserved in the herbarium in Corrientes, Argentina (CTES) contains the following lichens: *Degelia gayana* (Mont.) Arvidsson & D. Galloway, *Leioderma pycnophorum* Nyl., *Pseudocyphellaria divulsa*, *P. exanthematica* Lamb, *P. faveolata* (Delise) Malme and *Psoroma* cf. *araneosum* (Church. Bab.) Nyl. Secondly, a small number of specimens of *Pseudocyphellaria* Vainio, collected by E. Pisano during the visit of the American Geographical Society Southern Chile Expedition of 1959, is in the herbarium of the Natural History Museum in London (BM).

LICHEN HABITATS

The habitats of the lichens can be classified into eight groups.

(1) *Rocky shores*. A few small areas of boulders in a very shallow intertidal zone occur at Puntilla los Cisnes near the hotel jetty and there is some lichen stratification according to salinity and immersion in salt water evident in this habitat with a lower black zone dominated by *Verrucaria* Schrader, and a higher intertidal zone having species of *Caloplaca* Th.Fr., and *Lecanora* Ach. On the largest rocks which are immersed at high tide there is some development of the gelatinous maritime lichen *Turgidosculum* J. Kohlmeyer & E. Kohlmeyer.

(2) *Sand*. Sandy beaches and boulders mixed with sand occur in many sites around Laguna San Rafael, being particularly well-developed near Puntilla los Cisnes by the hotel jetty. Two lichens, *Placopsis pycnotheca* Lamb and *Psoroma cinnamomeum* Malme, grow readily in sand and appear to act as stabilizers and consolidators. Where wave-sorted boulders and stones offer a greater degree of stability, lichens, such as *Cladonia* J. Hill, and *Stereocaulon* Hoffm., are common on sand, soil and small stones, with larger boulders being covered with a mosaic of up to four species of *Placopsis* Nyl. In damper areas, where introduced grasses spread into sand at the coast, a vigorous growth of cyanobacterial lichens is found with the taxa *Leptogium menziesii* (Ach.) Mont., *Peltigera membranacea* (Ach.) Nyl., *P. scabrosa* Th.Fr., and *Sticta gaudichaldia* Delise, forming very large colonies and undoubtedly contributing appreciable amounts of fixed nitrogen from their cyanobacterial photobionts to the habitat. The growth of *Leptogium menziesii* in this habitat seems extremely rapid with the lichen actively overgrowing grass stems.

(3) *Lowland scrub communities*. Mainly *Berberis buxifolia* Lam., in swampy grassland supporting a rich cover of epiphytic lichens on twigs including: *Collema* Wiggers, *Dictyonema glabratum* (Sprengel) D. Hawksw., *Erioderma leylandii* (Taylor) Müll.Arg., *Hypotrachyna sinuosa* (Sm.) Hale, *Leioderma pycnophorum*, *Leptogium* (Ach.) S.F. Gray, *Nephroma antarcticum* (Jacq.) Nyl., *Normandina pulchella* (Borrer) Nyl., *Pseudocyphellaria berberina*, *P. corii-*

folia (Müll.Arg.) Malme, *P. crocata* (L.) Vainio, *P. mallota* (Tuck.) Magnusson, *P. piloselloides* (Räsänen) Magnusson, *Psoroma leprolomum* (Nyl.) Räsänen, *P. sphinctrinum* (Mont.) Nyl, *Sticta fuliginosa* (Hoffm.) Ach.

(4) *Recently—vegetated moraine surfaces*. Glacial drift and shallow moraines of the most recent San Rafael Glacier advances in the vicinity of the hotel provide a rich diversity of lichen habitats. (i) *Heathland* dominated by small shrubs such as *Berberis buxifolia*, *Empetrum rubrum* Vahl ex Willd., *Pernettya mucronata* (L.f.) Gaudichaud ex Sprengel, support varied lichen communities both in high-light situations in the crowns of shrubs, and also in low-light situations in the closed interior of bushes. Here, lichens with cyanobacteria as their photobiont are well-developed, e.g. *Degelia gayana*, *Erioderma leylandii*, *Pseudocyphellaria coerulescens* (Mont.) Magnusson, *P. hirsuta* (Mont.) Malme, *P. pluvialis* R. Sant., *P. scabrosa* R. Sant., and *Sticta fuliginosa*. Huge mounds of the golden yellow *Pseudocyphellaria berberina* are visually striking at the bases of shrubs and straggling through low vegetation (Fig. 2). (ii) *Moss heathland on sand* supports many different species of *Cladonia* and on stones and boulders in this habitat swards of *Stereocaulon* occur. On mosses, species of *Micarea* Fr., *Psoroma* Ach. ex Michaux, and *Dictyonema glabratum* (Fig. 3) occur, and on rocks which have been placed alongside the path to the glacier species of *Placopsis* and *Porpidia* Koerber are found. (iii) *Consolidated gravel of the airstrip* has a number of interesting lichens including species of *Cladonia*, *Collema*, *Peltigera* Willd., *Placopsis* and *Stereocaulon*. (iv) *Isolated trees and large shrubs* on moraine crests or alongside streams. The major substrates here are: *Drimys winteri* G. Forster, *Embothrium coccineum* G. Forster, *Escallonia alpina* Poepp. ex DC., *Lomatia ferruginea* (Cav.) R.Br., *Nothofagus betuloides* (Mirbel) Oerst., *N. nitida* (Phil.) Krasser, *Podocarpus nubigena* Lindl., *Psuedopanax laetevirens*

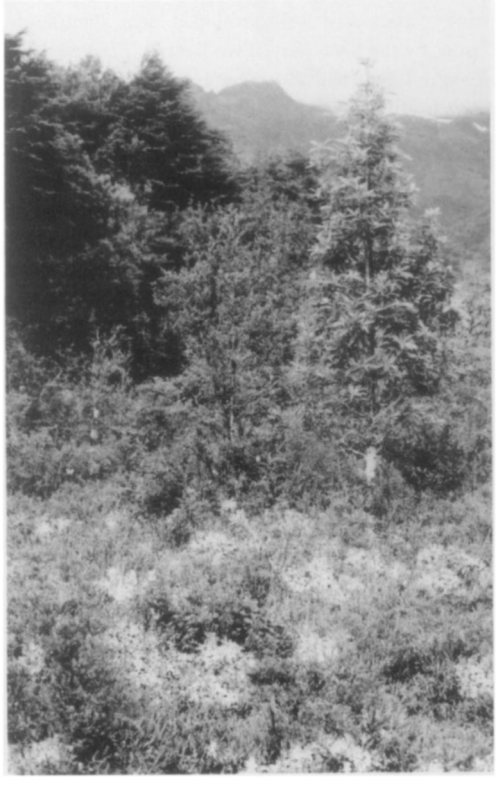

Fig. 2. Colonies of *Pseudocyphellaria berberina* (foreground) in heathland at Laguna San Rafael.

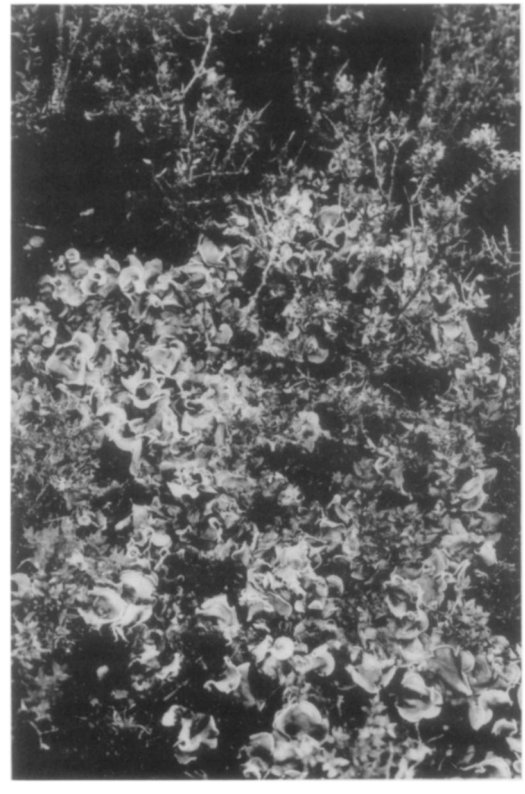

Fig. 3. Colonies of the basidiolichen *Dictyonema glabratum* amongst moss in heathland at Laguna San Rafael.

(Gay) Franchet, *Ribes magellanica* Poir., and these provide a variety of habitats for a varied lichen flora, especially on the trunks and in canopy branches (Fig. 4). Notable lichens here include: *Anzia afromontana* R. Sant., *Coccocarpia palmicola* (Sprengel) Arvidsson & D. Galloway, *Degelia duplomarginata* (P. James & Henssen) Arvidsson & D. Galloway, *Erioderma sorediatum* D. Galloway & P.M. Jørg., *Hypotrachyna oostingii* (Dey) Hale, *H. physcioides* (Nyl.) Hale, *Melanelia subglabra* (Räsänen) Esslinger, *Menegazzia opuntioides* (Müll.Arg.) R.Sant., *Metus efflorescens* D. Galloway & P. James, *Nephroma antarcticum*, *Pannoparmelia anzioides* Darbish., *Parmelia cunninghamii* Crombie, *Pseudocyphellaria bartlettii* D. Galloway, *P. coerulescens*, *P. coriifolia*, *P. encoensis* R.Sant., *P. meyenii* (Trevisan) D. Galloway, *P. nitida* (Taylor) Malme, *P. piloselloides*, *P. pluvialis*, *P. scabrosa*, *P. vaccina* (Mont.) Malme, *Psoroma calophyllum* Müll.Arg., *P. leprolomum*. *P. microphyllizans* (Nyl.) D. Galloway, *P. sphinctrinum*, *Sphaerophorus tener* Laurer, *Sticta ainoae* D. Galloway & J. Pickering, *S. caulescens* De Not., *S. hypochra* Vainio, *Usnea* sp. (rare on *Embothrium*).

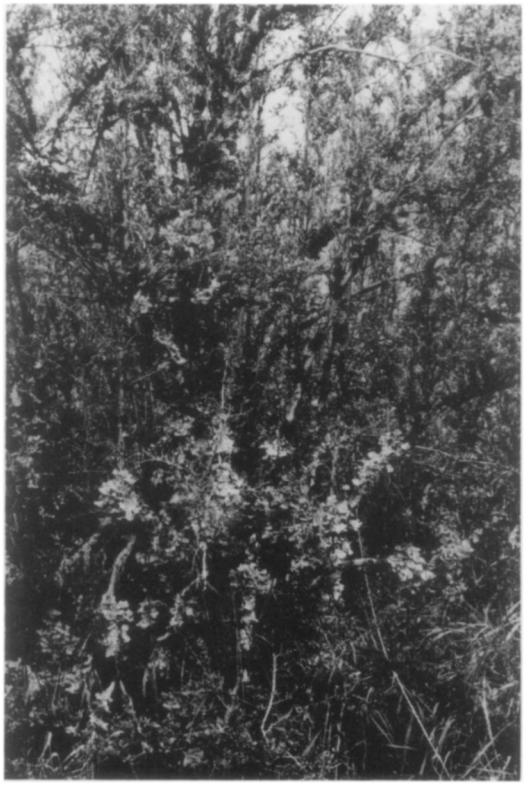

Fig. 4. *Nephroma antarcticum*, a prominent epiphyte of streamside trees and shrubs near Laguna San Rafael.

(5) *Rock faces and boulders near San Rafael Glacier*. Here the dominant lichens are mosaics of fast-growing species of *Placopsis* which develop on rock surfaces within a few years of their exposure from ice cover, the taxa most commonly encountered being *P. perrugosa* (Nyl.) Nyl., *P. patagonica* (Zahlbr.) Lamb, *P. cribellans* (Nyl.) Räsänen and *P. baculigera* Lamb. Older rock faces above the glacier have almost total crustose lichen cover. On lower slopes, rock faces near the snout of the glacier are dominated by extensive swards of *Stereocaulon*. Both of these genera have cyanobacteria associated in cephalodia and under the prevailing climatic conditions are probably effective fixers of atmospheric nitrogen. A study of the input of lichen-derived nitrogen from heterocyst fixation in cephalodia from these lichens which are a dominant part of the vegetation in these glacial environments would be an attractive and feasible field project for the future.

(6) *Rain forest from sea level to treeline*. This habitat is rather impenetrable because of the strong growth of understory bamboo. Here lichens are much less obvious in the deep shade, but instead are optimally developed on upper trunks and in the canopy. Common lichens here are *Pseudocyphellaria berberina*, *P. divulsa* and *P. flavicans* (J.D. Hook & Taylor) Vainio, all of which produce a large biomass, and species of *Leptogium*, *Nephroma*, and *Psoroma hispidulum* Nyl., and *Sphaerophorus* Pers.

(7) *Subalpine scrub at treeline*. The ecotone of forest-grassland or forest-scrubland is, in many parts of the Southern Hemisphere, a particularly rich zone of lichen diversity. Scrub communities in the head of Rio Salton were visited only once by a group of Venturers who brought back a small collection of lichens, the most notable being a species of *Siphula* Fr. Much more attention needs to be paid to this potentially rewarding, but extremely difficult to reach, habitat and it is to be hoped that subsequent Venturer-supported fieldwork in the area will concentrate on sampling lichen vegetation from alpine scrub and associated grasslands of the Cordillera frontal ridge systems.

(8) *Foliicolous lichens*. These are fast-growing lichens adapted to growth on the surface of leaves, usually the upper surface, but sometimes also on the lower surface or on leaf stalks. In the study area foliicolous lichens grow only on leaves of trees or shrubs

producing quantities of aromatic compounds, i.e. those leaves that are either sticky to the touch or which smell strongly aromatic when crushed. Major substrates are *Drimys winteri*, *Podocarpus nubigena* and *Pseudopanax laetevirens*. A byssoid lichen with pale green-white tubular lobes and small, pinkish globose apothecia (with small, bacillar, simple spores, 5.5–5.9 × 1.5–1.8 µm) grows on stems and leaves of *Drimys winteri*, and is close to the Australasian taxon, *Roccellinastrum neglectum* Henssen & Vobis (Henssen, Vobis & Renner, 1982; Kantvilas, 1990). It is significant that besides normal crustose foliicolous lichens, in this region several macrolichen genera grow on leaves of the above substrates including: *Leptogium*, *Nephroma*, *Pseudocyphellaria*, *Psoroma*, all growing to a considerable size (1–3 cm) on leaves only 1–4 years old.

The diversity and biomass of lichens having cyanobacterial photobionts in this region is particularly noteworthy and includes taxa from the genera: *Coccocarpia*, *Collema*, *Degelia*, *Dendriscocaulon* Nyl., *Dictyonema*, *Erioderma*, *Homothecium* Massal., *Leioderma*, *Leptogium*, *Nephroma*, *Parmeliella* Müll.Arg., *Peltigera*, *Placopsis*, *Pseudocyphellaria*, *Psoroma*, *Stereocaulon* and *Sticta*. Many of the species have rapid growth, produce a large biomass and appear to be strongly competitive and undoubtedly contribute substantial quantities of fixed nitrogen to the nutrient budget of the ecosystems in which they occur. This assemblage of genera, having a high potential for cyanobacterial nitrogen fixation, is a characteristic of Valdivian rain forest (Guzman, Quilhot & Galloway, 1990; Galloway, 1991a,b), and other similar formations of temperate rain forest in the Southern Hemisphere (Galloway, 1988b).

BIOGEOGRAPHICAL AFFINITIES

From the lichens collected at Laguna San Rafael, a number of biogeographical affinities of the lichen vegetation are apparent. Taxa endemic to southern South America are most richly represented in the lichen flora. Forest and heathland lichen communities have strong affinities with those of Valdivian rain forest seen most dramatically in the genera *Menegazzia* Massal., *Nephroma*, *Pseudocyphellaria* and *Psoroma*, and the intriguing monospecific *Lepolichen coccophorus* (Mont.) Trevisan, with a number of species apparently close to the southern limit of their distributions e.g. *Menegazzia hollermayeri* (Räsänen) R.Sant., *M. opuntioides*, *M. valdiviensis* (Räsänen) R.Sant., *Pseudocyphellaria divulsa*, *P. nitida*, *P. pilosella* Malme (from Lago Presidente Rios, Taitao Peninsula), *P. pluvialis*, *P. santessonii* D. Galloway (from Lago Presidente Rios, Taitao Peninsula), *P. valdiviana* (Nyl.) Follmann, and *Sticta ainoae*. A relationship with the lichen vegetation of Tierra del Fuego is seen for example in the taxa *Pseudocyphellaria berberina* (growing on the ground at the base of shrubs), *P. freycinetii* (Delise) Malme (from subalpine grassland/shrubland habitats above Lago Presidente Rios, Taitao Peninsula) and *P. vaccina* (Mont.) Malme.

Austral taxa reflecting relationships with other Southern Hemisphere lichen floras, such as New Zealand and Tasmania (Galloway, 1987, 1988a, 1991a), include: *Degelia duplomarginata*, *D. gayana*, *Erioderma leylandii*, *Leioderma pycnophorum*, *Leptogium menziesii*, *Menegazzia globulifera* R.Sant., *Nephroma cellulosum* (Ach.) Ach., *N. plumbeum* (Mont.) Mont., *Parmelia cunninghamii*, *P. protosulcata* Hale, *Pseudocyphellaria glabra* (J.D. Hook & Taylor) Dodge, *P. granulata* (Church.Bab.) Malme, *Psoroma sphinctrinum*, *P. leprolomum*, *Psoromidium versicolor* (J.D. Hook & Taylor) D. Galloway, *Sphaerophorus tener*, *Xanthoria ligulata* (Koerber) P. James.

Lichens with a cosmopolitan distribution are relatively few in the region but include: *Hypotrachyna sinuosa*, *Normandina pulchella*, *Pseudocyphellaria crocata*, *P. intricata* (Delise) Vainio and *Sticta fuliginosa*.

Lichens with known tropical affinities include *Anzia afromontana*, *Coccocarpia palmicola*, *Everniastrum sorocheilum* (Vainio) Hale ex Sipman, *Placopsis cribellans* and *Sticta sublimbata* (Steiner) Swinsc. & Krog.

A detailed lichen flora of the region is in preparation and will be published elsewhere.

LICHENS AND ENVIRONMENTAL CHANGE

It is known that metabolic processes such as photosynthesis, nitrogen fixation, mineral accumulation, and growth rates in lichens vary in response to seasonal and environmental changes and these responses, some very sensitive, have wide application in biomonitoring (Burton, 1986). Present trends of climate warming in both Northern and Southern Hemispheres are causing substantial recession of glaciers and icefields, and are creating new surfaces on which biota can become established.

Lichens, as early colonists in alpine and glacial environments, are spectacularly successful in recolonization of freshly-exposed rock, glacial outwash gravels and soils. In lateral moraine material bordering the San Rafael Glacier, small pebbles and freshly exposed rock races are rapidly colonized by minute tufts of the filamentous terrestrial alga *Trentepohlia* Martius, just visible with a × 10 hand lens, and within 1–2 years small colonies of the lichen *Placopsis* which utilize this photobiont appear. By 10–15 years, rock faces 10–50 m above the glacier are almost entirely covered with a mosaic of *Placopsis baculigera*, *P. cribellans*, *P. patagonica* and *P. perrugosa* (Fig. 5), with *P. perrugosa* being the most rapidly growing. These taxa are also found at lower levels on rocks and pebbles around the shores of the Laguna, and in sandy beaches near the abandoned hotel at Puntilla los Cisnes, the fast-growing, isidiate, *P. pycnotheca* is important in binding sand and small pebbles to provide a stable environment for the establishment of other lichens, (especially species of *Stereocaulon*), mosses and eventually higher plants. Both of these lichen genera are efficient nitrogen fixers, having secondary cyanobacterial photobionts present in external cephalodia. Future studies on growth rates and colonization ability of species of *Placopsis* will be important in understanding short-term environmental changes in the area.

Lewis Smith (1990) documents the role of lichens in a study of biological and environmental change in Antarctic terrestrial ecosystems on Signy Island in the South Orkneys, and makes a vigorous plea for implementing long-term monitoring studies using lichens and mosses, to determine the direction and rate of environmental and ecological changes, with particular regard to assessing resilience of ecosystems to, and their recovery from, such changes. In the Laguna San Rafael National Park, lichens provide a ready working tool for a variety of bio-monitoring studies in a range of environments from seashore to mountain top. Raleigh International, Venturer-supported studies on recent glacial movements of the calving San Rafael Glacier in 1991, and proposed studies on the nearby landbased San Quintin Glacier, will involve investigation of lichens, especially species of *Placopsis*, in determining rates of climatic and environmental change.

Lichens in alpine and high latitude environments worldwide are subject to high levels of u.v. radiation,

Fig. 5. Mosaics of *Placopsis* on rock faces above the San Rafael Glacier.

currently increased as a result of ozone thinning. It has recently been shown (Markham *et al.*, 1990) that absolute levels of photoprotective flavonoids in mosses from the Ross Sea region of Antarctica, collected between 1957 and 1959, correlate directly with measured levels of ozone over the period 1965–89, and suggest that flavonoid concentrations in herbarium specimens collected over a longer time scale have the potential to provide otherwise innaccessible data on historical trends in ozone levels in the Antarctic, and perhaps elsewhere. Lichens as a group produce a number of cortical screening compounds, especially carotenoids and usnic acid, which protect the sensitive photosystems of the lichen photobiont from damaging effects of radiation, and this makes lichens a potentially useful tool in monitoring longer-term effects of ozone thinning. Investigations of the lichen vegetation above treeline and on the nunataks and rocky ridges surrounding the North Patagonian Icecap, accessible from Laguna San Rafael, should yield important chemical data on levels of these photoprotective compounds. Direct comparisons should then be made with analogous habitats in high-alpine regions of New Zealand at similar latitudes. The use of lichens as indicators of climatic and environmental change in the temperate Southern Hemisphere, although still in its infancy, is a field of enormous and exciting potential.

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