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High diversity of lichens at 84°S, Queen Maud Mountains, suggests preglacial survival of species in the Ross Sea region, Antarctica

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Abstract Investigations of lichens collected in 1959/1960, 1963/1964 and 2003 from near the Beardmore Glacier in the southern Ross Sea region (84°S) have more than doubled the number of known lichen species in the area to around 30. The ranges of 15 species have been extended to 84°S. A lichen diversity hotspot has also been found along Ebony Ridge and its associated peaks where 28 of the species occur, a number equivalent to more northerly sites in the Ross Sea (e.g. Botany Bay 77°S). Furthermore, 6 species had been previously recorded only from the Antarctic Peninsula region. In agreement with previous studies on mites and springtails from the same area, we suggest that these populations represent relicts that predate the present Ross Ice Shelf extension, with a possible age of 2,000,000 years or older.

Keywords Relict · Collembola · Beardmore Glacier · Mosses · Diversity · Lichens

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Introduction

There is a growing interest in the distribution of terrestrial organisms in Antarctica because of the potential use of biodiversity as an indicator or predictor of the effects of climate change. For example, the New Zealand Latitudinal Gradient Project (LGP, http://www.lgp.aq) was set up specifically to enhance our understanding of the distribution and diversity of both marine and terrestrial biota, in the Ross Sea region, as well as factors that control present-day distributions (Howard-Williams et al. 2006, 2010). The main biological programme in SCAR, Evolution and Biodiversity in the Antarctic (EBA, http://www.eba.aq), also seeks to understand the properties and dynamics of present-day Antarctic ecosystems and to predict how organisms and communities will respond to current and future environmental changes. As a result of such major collaborative and multidisciplinary programmes, our knowledge of Antarctic biodiversity has been considerably advanced.

In an assessment of the diversity and biogeography of the Antarctic flora, Peat et al. (2007) concluded that a clear diversity gradient for lichens exists along the Antarctic Peninsula, with a strong decline, albeit in steps, in species richness from 62°S to around 70°S. However, they did not find any current evidence for a diversity gradient along the Victoria Land coast and into the Transantarctic Mountains from 72°S to the southernmost records at 86°29′S. They noted, however, that there have been very few collections made at some latitudes. In particular, there have been no recent botanical surveys south of the McMurdo Dry Valleys (77–79°S). Knowledge of the terrestrial biodiversity at high latitude sites in the southern Ross Sea region is a key to understanding distribution patterns along the Ross Sea coast. Such information would confirm the presence or absence of a biodiversity cline and would provide potential indicator species for climate change.

The use of any cline in biodiversity to predict the effects of climate change in polar regions is founded on the premise that the lichens present are in equilibrium with the climate and that any changes in environmental factors would, therefore, lead to consequential alterations in lichen distribution and/or diversity. However, there is growing evidence that the distributions of some organisms in Antarctica (e.g. Collembola) are influenced by historical events and local survival (Stevens et al. 2006; Nolan et al. 2006; Convey and Stevens 2007; Convey et al. 2008; Hawes et al. 2010; Torricelli et al. 2010), a situation that would tend to mask any climatic effects. Peat et al. (2007) also note that the patterns of endemism amongst lichens suggest that a proportion of the lichen flora may have an ancient vicariant distribution. Again, better knowledge of lichen systematics, together with biodiversity of these deep southern sites, particularly in combination with modern molecular techniques, may help clarify the origins of, and the factors controlling, present-day lichen populations.

Table 1 Locations of the collection sites: the sites in the Mt. Kyffin area (A to N) are marked in Fig. 2 and used for lichen distribution analysis in Table 2

Site code (Fig. 2, Table 2)	Name[g]	Latitude	Longitude	Altitude (m)
	Mt. Kyffin area			
A	Beardmore coastline	83°45′S	171°00′E	~150
B	Airdrop Peak	83°45′S	172°48′E	890
C	Ebony Ridge[a]	83°46′S	172°40′E	450–650
D	Mt. Kathleen	83°46′S	172°48′E	900
E	Mt. Harcourt[f]	83°48′S	171°38′E	1,535
F	Mt. Kyffing[g]	83°48′S	171°38′E	1,670
G	Guardian Nunatak[b]	83°49′S	173°41′E	210
H	Prospect Spur	83°57′S	173°25′E	~1,200
I	Mt. Cyril	84°02′S	172°35′E	1,190
J	Chevron Rocks	84°07′S	173°10′E	~1,100
K	Peak 1[c]	84°08′S	173°25′E	876
L	Peak 2[d]	84°12′S	173°28′E	2,380
M	Siege Dome[e]	84°16′S	172°22′E	1,490
N	Garden Spur	84°30′S	174°45′E	690

[a] Called Black Ridge by 1959 group
[b] Called Sentinel Nunatak by 1959 group
[c] Called Beehive Dome by 1959 group, apparently not named
[d] Called Mt Patrick by 1959 group, apparently not named
[e] Called Christmas Dome by 1959 group
[f] Collections were made mainly on spurs leading up to summit
[g] Names are those accepted by the USA Geological Survey

Here, we present a synthesis of lichen collections taken from near 84°S in the Transantarctic Mountains of the Ross Sea Region. The area is south of the Beardmore Glacier and within 2° latitude of the southernmost known collection of lichens (Broady and Weinstein 1998). The collections were made by New Zealand-led groups in 1959 and 1963 and a more recent visit in 2003.

Methods

The lichen samples considered here were collected by three separate research groups that visited the extreme south of the Ross Sea, Queen Maud Mountains. A list of the sites is given in Table 1, and they are marked on the maps in Figs. 1 and 2.

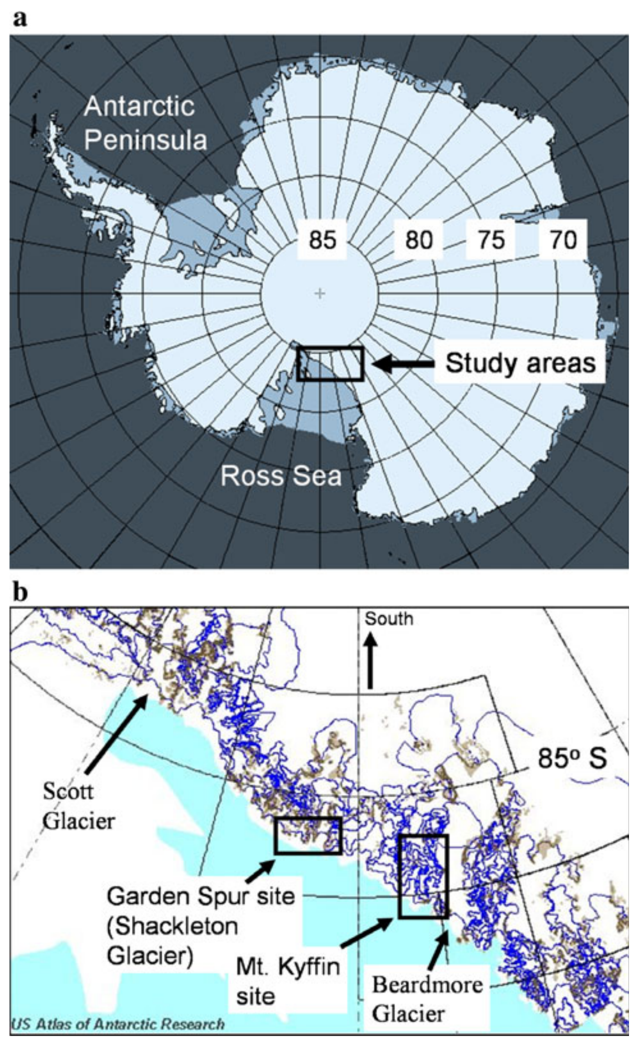

Fig. 1 Location of the collection sites at the southern part of the Ross Sea in Antarctica; **a** the general location of the collection area, *numbers* are the latitude in degrees south; **b** more detailed map of the *inset box* in **a**. Actual collection sites are shown in Fig. 2. The maps are sourced from the online Atlas of Antarctic Research

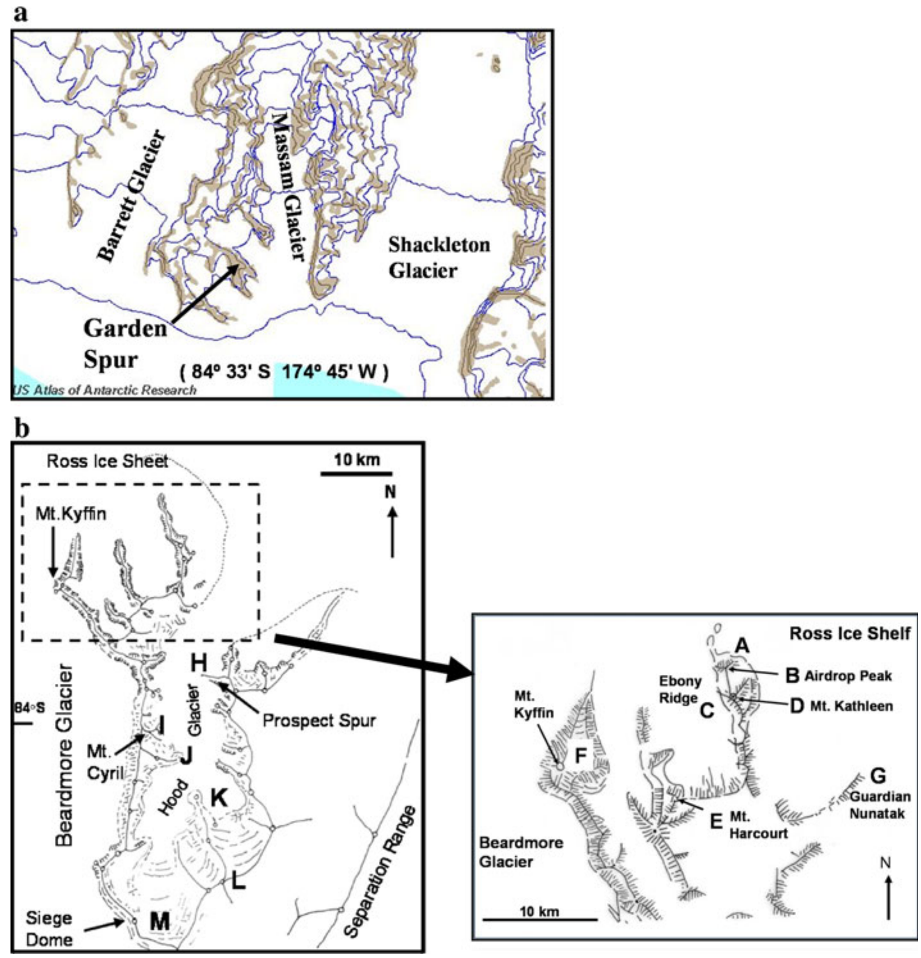

Fig. 2 Detailed maps of collection sites. **a** Location of Garden Spur adjacent to the Massam Glacier and near the Shackleton Glacier. **b** Collection sites in the vicinity of the Beardmore Glacier; *right hand panel* is an enlargement of the marked area in the more general *left hand map*. The *letters* on the maps mark the actual collection sites and are named in Table 1. Maps are modified from New Zealand Alpine Journal (Tyndale-Biscoe 1960a). Map **a** is sourced from the online US Atlas of Antarctic Research

The first collections were by an eight-member group from the New Zealand Alpine Club led by R. W. Cawley (Cawley 1960; Tyndale-Biscoe 1960a). The group carried out extensive surveys from 23rd November 1959 to 7th January 1960 in the vicinity of Mt. Kyffin (83°48′S, 171°38′E, 1,670 m) immediately south of the Beardmore Glacier, covering an area measuring approximately 15 by 60 km, 83°45′–84°13′S, 171°30′–172°45′E (Fig. 2). Over 200 samples of lichens were returned to New Zealand and are now archived in the herbarium of the Dominion Museum of New Zealand, Wellington (WELT). During curation activities, the samples were inspected and identified to the lowest taxonomic level possible, by R.D. Seppelt in 2005. In Table 1, the sites visited by this group have been verified using the route map in Cawley (1960) and Tyndale-Biscoe (1960a), together with the narrative of the journey in the same reports, and with the collection date and collectors name marked on each sample. Where necessary, the names of the localities have been changed to conform to those accepted by United States Board on Geographic Names and marked on the appropriate maps.

The second group to visit the area was the southern party from the New Zealand Geological Survey Antarctic Expedition (NZGSAE) 1963–64, who collected near the Shackleton Glacier at Garden Spur (84°33′S 174°45′W, 690 m, which they so named because of the rich flora found there; Figs 1, 2). A small number of samples from the latter site, collected by McGregor VR, around 10, are also archived in WELT.

The third group was a research party led by the University of Waikato who visited a small area near Mt. Kyffin (within the area surveyed by the New Zealand Alpine Club) from 7th to 11th January 2003, when around 200 samples were collected, predominantly from Ebony Ridge and its vicinity (Figs. 2, 3). The samples are at present located in the private herbarium of R. Türk and at MAF herbarium, Madrid (see authors and Table 4). Identification was by standard taxonomic microscopy and by molecular methods for the Lecideaceae (Ruprecht et al. 2010).

Results

A total of 410 samples was examined, about 200 collected in 1959/1960 and about 200 in 2003 from the Mt. Kyffin/Beardmore Glacier area, and 10 from Garden Spur in

Fig. 3 Photographs of **a** A ridge site forming part of Ebony Ridge near Mt. Kyffin, 83 46′S, 172 40′E, near to the Beardmore Glacier. The sharp, asymmetric peak of Mt. Kyffin can be seen in the *top*, *left corner* of the photograph. The pole on the ridge is a crevasse pole about 1.5 m high. **b** Large thallus of *Pseudephebe minuscula* growing on a greywacke boulder; *bar* is 20 cm

1963/64. The species found and their locations are provided in Table 2. Five named lichen species were found at Garden Spur and two more identified to genus level. One of the latter is an *Acarospora* species which is a member of the brown *Phaeothallia* group [*Acarospora* sect. *Phaeothallia* (H.Magn.) Räsänen]; this represents a range extension within the Ross Sea as *Phaeothallia* group species have only been reported from Botany Bay (Seppelt et al. 2010) and Terra Nova Bay (Castello and Nimis 2000), in both cases *Acarospora williamsii*. The *Lecidea* samples are most likely to be all forms of *L. cancriformis* (Ruprecht et al. 2010). Based on these records, and including the two taxa yet to be identified with certainty, 7 species were found at Garden Spur. Of these, *Sarcogyne privigna* was not found at the Mt. Kyffin area although it is already known from further south in the La Gorce Mountains, (86°29′S, see Table 3). This number of species makes the site slightly richer than the four sites further south, which have more than one lichen species present (Table 3).

The lichen diversity at the Mt. Kyffin site (this includes all sites on the detailed map Fig. 2a) was substantially richer (Table 2). A total of 27 named species were found with another 5 identified only to genus level. As for the Garden Spur records, the samples of *Acarospora* (all *Phaeothallia* members), *Caloplaca* and *Lepraria* are each expected to represent single species, although their specific identity remains to be determined. The *Lecidea* samples are all expected to be *L. cancriformis*, whilst the *Buellia* samples could be an unknown number of species. Excluding the latter two groups, the total number of species would be 30. This total far exceeds that from any other site at this latitude and is just greater than the 29 lichen species reported for Botany Bay, one of the richer plant sites in the Ross Sea region with a diversity exceeded only by Edmonson Point, Terra Nova Bay (Cannone and Guglielmin 2010; Seppelt et al. 2010). All of these species, with the exception of *Caloplaca citrina* and *Umbilicaria aprina*, are found at Ebony Ridge (site C, Fig. 2) and its associated summits (Airdrop Peak, site B; Mt. Kathleen, site D; Mt. Harcourt, site E; Fig. 2, Table 1). This makes the location a hotspot for lichen diversity and a typical view of the ridge is shown in Fig. 3a and a closer view showing the surprising size of some lichen thalli in Fig. 3b.

As a result of these collections, the latitudinal ranges of 15 of the 27 named species have been extended considerably further south (Fig. 4). About half of the species were previously known in Southern Victoria Land. However, the remainder appear to have been reported from, or close to, the Antarctic Peninsula giving range extensions in the order of 14 degrees of latitude. The high lichen diversity in this area reflects the presence of a substantial number of species not previously reported for the Ross Sea region.

In addition to the lichens, one lichenicolous fungus, *Taeniolella* sp., and four moss species were found, all on Ebony Ridge (site C) or Mt. Harcourt, (site E) (Table 2). All three named species represent an extension to their known distribution, from Southern Victoria Land (around 78°S) for *B. pseudotriquetrum* and *Schistidium antarctici*, and from the Antarctic Peninsula and from Marie Byrd Land, 78°S (Ochyra et al. 2005), for *Schistidium urnulaceum*.

Discussion

The collections reported here from Garden Spur and the Mt. Kyffin area have approximately doubled the number of lichen species known from the Queen Maud Mountains, in the southern Ross Sea region. These findings provide little support for a major cline in lichen diversity with increasing

Table 2 Sites at which the different lichen and moss species were found; names of the sites can be found in Table 1 and the geographical locations in Fig. 2

Species	Collection sites—see Table 1 for names and Fig. 2 for location													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Lichens														
Acarospora gwynnii C.W. Dodge & E.D. Rudolph	X	X	X	X	X	X	X							X
Acarospora sp.					X	X					X			
Buellia frigida Darb.			X		X									
Buellia latemarginata Darb.					X									
Buellia sp.		X	X	X	X	X					X	X		
Caloplaca citrina (Hoffm.) Th. Fr.											X			
Caloplaca sp.			X		X	X								
Candellariella flava (C.W. Dodge & G.E. Baker) Castello & Nimis			X									X	X	
Carbonea vorticosa (Flörke) Hertel			X											
Hymenelia glacialis (C.W. Dodge) Ovstedal			X											X
Lecanora expectans Darb.				X										
Lecanora physciella (Darb.) Hertel		X												
Lecanora polytropa (Hoffm.) Rabenh.			X											
Lecidea cancriformis C.W. Dodge & G.E. Baker			X	X	X	X								
Lecidea sp.			X	X	X	X							X	X
Lecidella sp. (cf. *siplei*)			X											
Lepraria sp.					X									
Micarea cf. *turfosa* (A. Massal.) Du Rietz			X											
Pleopsidium chlorophanum (Wahlenb.) Zopf			X											
Polysporina frigida Kantvilas & Seppelt			X											
Pseudephebe minuscula (Nyl. ex Arnold) Brodo & D. Hawksw.			X	X	X	X	X	X	X					X
Pseudephebe pubescens (L.) M. Choisy			X											
Psoroma hypnorum (Vahl) Gray			X											
Rhizocarpon adarense (Darb.) I.M. Lamb			X											
Rhizocarpon geographicum (L.) DC.			X	X	X	X				X	X			X
Rhizocarpon nidificum (Hue) Darb.			X											
Rhizocarpon superficiale (Schaer.) Malme			X											
Rhizoplaca melanophthalma (Ram.) Leuckert & Poelt			X	X		X								
Sarcogyne privigna (Ach.) A. Massal.														X
Umbilicaria aprina Nyl.									X					X
Umbilicaria decussata (Vill.) Zahlbr.			X		X									
Usnea sphacelata R. Br.			X		X	X			X					
Xanthomendoza borealis (R.Sant. & Poelt) Søchting, Kärnefelt & S. Kondratyuk					X									
Number of species at location (includes unknown single species)	1	3	23	8	14	10	2	1	3	1	4	2	2	7
Lichenicolous fungus														
Taeniolella sp.			X											
Mosses														
Bryum pseudotriquetrum (Hedw.) Gaertn., B. Meyer & Scherb.			X											
Schistidium antarctici (Card.) Savicz & Smirnova					X									
Schistidium sp.					X									
Schistidium urnulaceum (Müll.Hal.) B. G. Bell			X											

Symbol X means the lichen or moss was found at least once at that particular site

Table 3 Sites south of 85°S latitude for which more than one lichen species has been reported; modified from Table 6, Øvstedal and Smith (2001)

Site	Species
QMM, Mt. Scudder—86°07′S, 149°36′W	*Buellia frigida*
	Buellia grisea
	Carbonea vorticosa
	Lecidea cancriformis
	Rhizoplaca melanophthalma
QMM, Mt. Durham—85°31′S, 151°12′W	*Buellia grisea*
	Lecidea cancriformis
	Pseudephebe minuscula
	Rhizoplaca melanophthalma
Thiel Mt., (several sites)—85°02′S, 91°00′W	*Acarospora gwynii*
	Acarospora williamsii
	Candelariella flava
	Lecanora sverdrupiana
	Rhizocarpon geographicum
La Gorce Mt., Mt. Roland—86°29′S, 149°36′W	*Carbonea vorticosa*
	Lecidea cancriformis
	Sarcogyne privigna

Two additional lichen species, *Lecanora expectans* and *Umbilicaria decussata*, have been reported once from two other sites giving a total of 14 species previously known to occur south of 85°S

latitude within the Ross Sea Region. Specifically, the total number of lichen species found at 84°S exceeds that found in the Dry Valleys (unpublished data) has one more species than at Botany Bay (Seppelt et al. 2010) and represents approximately 60% of the number of lichens reported from Northern Victoria Land (Cannone 2006; Cannone and Seppelt 2008; Cannone and Guglielmin 2010). Around 30 lichen species have also been reported for the continental coastal site Larsemann Hills (Singh et al. 2007). However, there may be some evidence for a relationship between species diversity and increasing altitude. The high species numbers at Ebony Ridge and Garden Spur strongly suggest that the lower altitude sites along the Ross Ice Shelf are the sites of highest diversity. In the vicinity of Mt. Kyffin, the other more inland sites had no more than four lichen species each. This contrasts with the McMurdo Dry Valley where lichen diversity and abundance is greater along ridges of the valley sides above around 800 m altitude because of higher atmospheric humidity and moisture derived from clouds. There is a major decline in the number of moss species from nine at Granite Harbour and in Northern Victoria Land (Cannone and Seppelt 2008) to four species at Mt. Kyffin and none at any site further south, including Garden Spur (note, however, that the naming description for Garden Spur says it was named "because of the rich flora of mosses, algae and lichens found there").

Ebony Ridge and its summits, Mt. Kathleen, Airdrop Peak and Mt. Harcourt, stands out as an exceptional site with only three of the 31 species now known for the area not being found there, *Umbilicaria aprina*, *Caloplaca citrina* and *Sarcogyne privigna* (Garden Spur only). The majority of the named lichens at this site can be allocated to three main groupings (Table 4). The first group of 9 species (*Acarospora gwynnii*, *Buellia frigida*, *Lecanora polytropa*, *Lecidea cancriformis*, *Pleopsidium chlorophanum*, *Pseudephebe minuscula*. *Rhizoplaca melanophthalma*, *Umbilicaria decussata* and *Usnea sphacelata*) corresponds to a "tolerant" set of lichens proposed by Øvstedal and Smith (2001) that are typical of cold, dry and windy habitats. This appears to be a widespread and relatively consistent grouping. Perhaps, not surprisingly, seven of these species are already known from sites further south (Fig. 4). Four species (*Candelariella flava*, *Caloplaca* sp. *Lecanora expectans* and *Xanthomendoza borealis*, at Ebony Ridge, plus *C. citrina* from another site) are often found growing on moss but also occur on rock and gravels. They are usually found on gravel and sandy soil in the 84°S region. Two of the species (*C. flava* and *L. expectans*) were not unexpected as they are known from more southern sites (Fig. 4). However, of note is the presence of *X. borealis*, a nitrophilous species usually associated with nutrient-rich sites, particularly bird colonies.

The most surprising and unexpected grouping is that of the six species categorised as Peninsular in Øvstedal and Smith (2001). None of these species appear to have been previously reported from the Ross Sea region, so their occurrence represents a range extension of over 13 degrees latitude. There are several possible explanations for the occurrence of this Peninsula grouping at Ebony Ridge.

First, previously inadequate collections; this is the most obvious explanation although we suggest it is inappropriate in this case. Peat et al. (2007) analysed all the records for Antarctica and concluded that, overall, it had been well sampled although obviously not so at these extreme

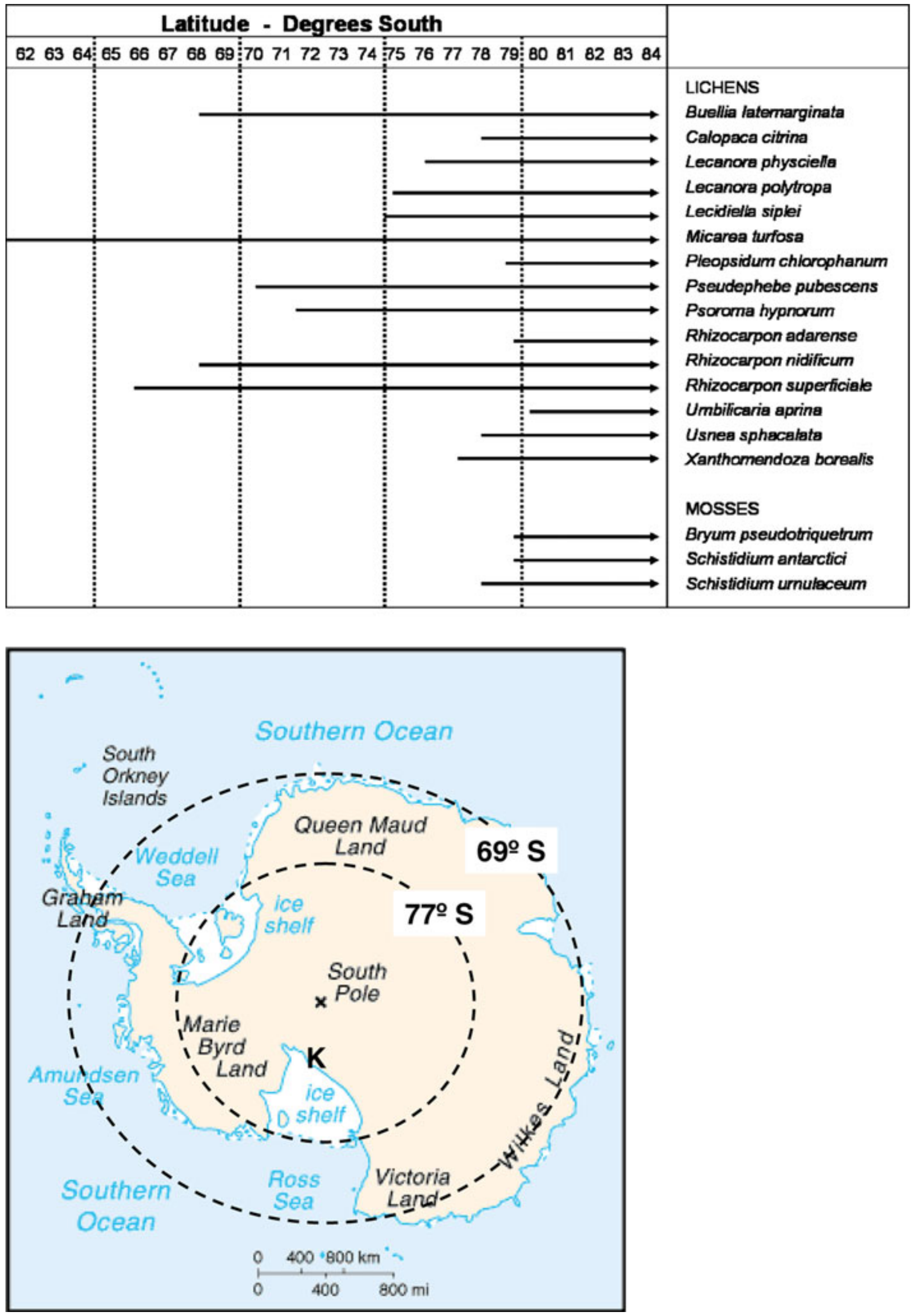

Fig. 4 Increase in range for all lichen and moss species not previously found at 84°S or higher latitudes. *Upper panel horizontal arrows* indicate the increase in latitude from *left* to *right*. *Lower panel* is a map of Antarctica showing where the main previous southern limits were, around 77°S in the Dry Valleys region and around 69°S in the Antarctic Peninsula

southern sites. All the authors of this paper have extensively collected at other sites along the Ross Sea coast including at Botany Bay, the Dry Valleys and Cape Hallett. One author (RDS) has visited and collected extensively along the continental coast and inland from 40°E to the Ross Sea. In Northern Victoria Land and at other sites, Nimis and co-workers have thoroughly analysed herbarium records, in particular for northern Victoria Land (Castello and Nimis 1995, 2000; Castello 2003). Yet none of these authors has reported any of the lichens between Mt. Kyffin and the Antarctic Peninsula. If there were only one or two species that fell into this grouping, then under-collecting might be a strong possibility. However, with 6 species, we consider this to be highly unlikely.

A second possibility is introduction by visiting scientists. We suggest that this is also highly unlikely as the Ebony Ridge site has been rarely visited and any such quarantine breaches would be far more likely to have occurred at more northerly sites.

A third possibility is the long-distance dispersal. The presence of the other lichen species that are more typical of the Ross Sea, especially the tolerant group, shows that this might be a possibility. However, it is highly unlikely that this has occurred for this number of species over 14

Table 4 Lichens collected in the Mt. Kyffin (Beardmore Glacier) area and categorised according to their distribution pattern (Cosmopolitan, Bipolar or Endemic) according to Øvstedal and Smith (2001) and to their proposed origin/substrate (moss—typically found on dry moss; tolerant—members of broadly distributed group tolerant of cold, dry, windy conditions, after Øvstedal and Smith (2001); peninsula—only reported from the Antarctic Peninsula region outside this site, after Øvstedal and Smith (2001)

Species[a]	Cosmopolitan	Bipolar	Endemic	Group	Sample location[b]
Acarospora gwynnii			X	Tolerant	MAF T WELT
Acarospora sp.				Tolerant	T WELT
Buellia frigida			X	Tolerant	MAF WELT
Buellia latemarginata			X	Peninsula	WELT
Buellia sp.			X		T WELT
Caloplaca citrina	X			Moss	WELT
Caloplaca sp.				Moss	WELT
Candelariella flava			X	Moss	WELT
Carbonea vorticosa		X		Tolerant	MAF
Hymenelia glacialis			X		T
Lecanora polytropa		X		Peninsula	MAF T
Lecanora expectans			X	Moss	WELT
Lecanora physciella			X		WELT
Lecidea cancriformis			X	Tolerant	MAF WELT
Lecidea sp.					T WELT
Lecidella cf. *siplei*			X		T
Lepraria sp.					WELT
Micarea aff. *turfosa*		X		Peninsula	MAF
Pleopsidium chlorophanum		X		Tolerant	WELT
Polysporina frigida			X		T
Pseudephebe minuscula		X		Tolerant	MAF T WELT
Pseudephebe pubescens		X		Peninsula	MAF T
Psoroma hypnorum	X			Peninsula	T
Rhizocarpon adarense			X		T
Rhizocarpon geographicum	X				T WELT
Rhizocarpon nidificum			X	Peninsula	T
Rhizocarpon superficiale		X			MAF T
Rhizoplaca melanophthalma		X		Tolerant	WELT
Umbilicaria aprina		X			WELT
Umbilicaria decussata		X		Tolerant	MAF T WELT
Usnea sphacelata		X		Tolerant	MAF T WELT
Xanthomendoza borealis		X		Moss	WELT
Taeniolella sp. (lichenicolous fungus)					MAF

[a] Species authorities are given in Table 2

[b] Herbaria holding samples of the species, MAF—MAF Herbarium, Madrid; T—R Türk, Salzburg; WELT—Dominion Museum, Wellington

degrees of latitude without their occurrence at intermediate sites.

A fourth possibility is that these lichens represent relicts that have survived in situ from preglacial times when the climate was more similar to that presently occurring in the Antarctic Peninsula. This suggestion is supported by similar studies on the unique springtails (Collembola) and mites (Acari) collected from the same area (e.g. Tyndale-Biscoe 1960b; Strandtmann 1967) and including more recent molecular studies (Stevens and Hogg 2003; Demetras et al. 2010). One difficulty with this suggestion for the lichens is not so much the occurrence of the group in the Mt. Kyffin area, but their absence in the rest of continental Antarctica. If they are relict, then it is possible that they were once present along the entire Ross Sea coast during the interglacial periods. The disappearance of these populations from intervening areas whilst they continued to survive at Mt. Kyffin is interesting. However, one possibility is that increased snow fall during the glacial advance may have covered all potential lichen habitats and led to their extinction in the intermediate areas. The negative effect on lichens of extended snow duration is well known (Benedict 1990; Körner 1999; Pomeroy and Brun 2001), and the negative effect on activity under present conditions has been demonstrated (Pannewitz et al. 2003; Schroeter et al. 2010). The site at Mt. Kyffin would have been protected because, as often found in alpine areas, it is a sharp ridge that although receiving substantial snow fall the habitat remains available for lichens because is kept clear of deep snow fall by the wind. Furthermore, with distance from the open sea increasing as the ice sheet advanced, there would have been a concomitant decline in precipitation.

If the lichens do represent a relict group, then how long have they survived at 84°S? Although glaciation of the Antarctic continent started some tens of millions of years ago, there is recent evidence from drilling near Ross Island that the Ross Ice Shelf has disappeared on several occasions, resulting in the Ross Sea becoming a marine embayment (Naish et al. 2009). This is supported by modelling that shows major collapses of the West Antarctic ice sheet, the so-called super-interglacials, as recently as 200 k years ago (Pollard and DeConto 2009), together with more recent estimates of ice extension (Storey et al. 2010), which show that ice-free areas almost certainly existed at these high latitudes even during the last glacial maximum. Accordingly, the relict populations may be as young as 200 k years. Most importantly, there was a period when ice cover was much greater than that presently found. Such extensive glaciations could have contributed to the elimination of the intermediate populations of Peninsular lichens. Future sampling together with the application of modern molecular techniques will be necessary to test this hypothesis.

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