Antarctic Science 34(6), 423–431 (2022) doi:10.1017/S0954102022000396

The distribution of lichens and mosses at Edward VII Peninsula, Marie Byrd Land, Antarctica

RYSZARD OCHYRA [1], DAG O. ØVSTEDAL [2] and PAUL A. BROADY [3]

[1]*Laboratory of Bryology, Władysław Szafer Institute of Botany, Polish Academy of Sciences, Lubicz 46, 31-512 Kraków, Poland*
[2]*Department of Natural History, University Museum, PO Box 7800, N-5020 Bergen, Norway*
[3]*School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch 8140, Aotearoa/New Zealand*
paul.broady@canterbury.ac.nz

Abstract: This is the first detailed study of the distribution of mosses and lichens at Alexandra Mountains and Rockefeller Mountains, Edward VII Peninsula, Antarctica. A total of 418 samples was collected on 21 nunataks in the summer of 1987–1988. Lichens included 44 taxa, bringing the total known from Edward VII Peninsula to 50. Ten lichen species were new records for the Continental Antarctic zone, whilst only six were endemic to that zone. There were six species and one variety of moss, bringing the total known from Edward VII Peninsula to seven species and one variety. These included the first record of a species of *Orthotrichum* in Continental Antarctica. Two other species and a variety were new records for Edward VII Peninsula. Overall, the flora was species rich for a Continental Antarctic region and was comparable with the species-rich sites of Botany Bay and Kar Plateau, which are at approximately the same latitude (77°S) in southern Victoria Land. This rich flora was probably supported by a reliable summer water supply from melting snowfall and snowdrift and by the range of microenvironments at nunataks with different degrees of nutrient enrichment from nesting birds.

Received 17 June 2022, accepted 16 September 2022

Key words: Alexandra Mountains, bryophytes, Continental Antarctic zone, floristics, new records, Rockefeller Mountains

Introduction

Edward VII Peninsula is nearly completely ice-covered and forms the north-western extremity of Marie Byrd Land (United States Geological Survey 1972). Rock exposures occur at eight nunataks in Alexandra Mountains and at 17 nunataks in Rockefeller Mountains (77°00'–78°30'S, 153°00'–157°00'W; Figs S1–S19).

The occurrence of mosses and lichens in Alexandra Mountains was noted by Prestrud during the Norwegian Antarctic Expedition of 1910–1912, the first to reach a nunatak (in Amundsen 1912, p. 249). Two months later, the Japanese Antarctic Expedition of 1910–1912 briefly visited the same area but did not access rock exposures (Dagnell & Shibata 2011, p. 200). The region was next visited by the first Byrd Antarctic Expedition (1928–1930) and 'bits of gray lichens and in just one place some greenish moss-like growth' was noted in Rockefeller Mountains (Gould 1931, p. 20). During the Second Byrd Antarctic Expedition to Marie Byrd Land (1933–1935), collections and detailed ecological observations were made by Siple (1938, p. 490), but these were predominantly in Ford Ranges, 130 km further east (77°S, 145°W), and only one nunatak, Washington Ridge, was visited on Edward VII Peninsula. Five moss species were described by Bartram (1938), two of which were found in Rockefeller Mountains. The lichens were identified by Dodge & Baker (1938). Collections were made from 11 nunataks in Rockefeller Mountains by Perkins (1945, p. 282) during the United States Antarctic Service Expedition (1939–1941) and on Washington Ridge by Rudolph (1967). The lichens were described by Dodge (1973). Unfortunately, the inaccurate lichen nomenclature of Dodge & Baker (1938) and the unorthodox species concept of Dodge (1973) have prevented comparison of their results with those of other Antarctic collections (Øvstedal & Lewis Smith 2001).

During summer 1987–1988, a combined geological and biological expedition visited all but four of the 25 nunataks in Alexandra Mountains and Rockefeller Mountains (Adams *et al.* 1989). Reports were made of observations on birds (Broady *et al.* 1989) and on field collections of algae (Broady 1989). Collections of lichens and mosses were made by one of us (P.A. Broady) at each nunatak, and identifications using a small subset of these resulted in a preliminary list of 23 lichen and six moss species together with some observations on their ecology (Broady 1989).

The present account is the result of a detailed examination of all of these samples and has resulted in

an extended and updated list of species together with information on their distributions amongst the nunataks. A new lichen and a new fungus species have been established (Elix *et al*. 2020, Øvstedal *et al*. 2021).

Methods

Study area

A general description of the region and a first account of the geology have been provided by Wade (1945). The geological mapping was updated and overviewed and rock-dating provided by Adams *et al*. (1995). The geology comprises granitoids, metasediments and migmatite. Nunataks range from rock exposures of just a few hundred square metres (e.g. Mount Frazier) to the largest, Mount Paterson, which has a length of > 4 km of branched, low ridges. Rock exposure in Alexandra Mountains is considerably less than in Rockefeller Mountains and is mostly steep slopes and cliffs of two north- to north-east-facing escarpments (Figs S2–S19). Summits are from ~419 to 1174 m altitude and ice surfaces immediately surrounding nunataks are at ~400–1000 m altitude.

During the period of 28 November 1987–11 January 1988, meteorological observations were taken twice a day at ~10h00 and 22h30 solar time. Air temperatures ranged from -17°C to -2°C. Cloud cover was extensive on 76% of observations. Wind occurred on 87% of observations but did not exceed 20 kn and was usually < 10 kn and from the east to north-east. Snowfall or snowdrift occurred on 25 days (54% of days).

Of the geobotanical zones recognized in Antarctica, the two mountain ranges have characteristics most similar to the Slope Region of the Continental Antarctic Province (Øvstedal & Lewis Smith 2001, p. 5, Ochyra *et al*. 2008, p. 3).

Samples

A total of 418 samples was obtained (Table I & Fig. S1) from 6 of the 8 nunataks of Alexandra Mountains (Mount Manger and Mount Youngman were inaccessible) and 15 of the 17 nunataks of Rockefeller Mountains (Mount Shideler and Melbert Rocks were not visited). The nunatak of origin was not noted for samples from two groups of three closely adjacent nunataks in Rockefeller Mountains (Mounts Frazier, Jackling and Fitzsimmons and Mounts Butler, Gould Peak and Tennant Peak), and each group was treated as a single location.

Sampling was opportunistic, and numbers of samples at each location ranged from two at Fokker Rocks to 53 at Mount Nilsen. This variability was due to a combination of 1) the duration of the visit, 2) the accessibility of rock exposures, 3) the weather conditions and 4) a perceived, subjective estimate of the diversity of lichens and mosses at each nunatak. A greater intensity of sampling was probable for longer visits during good weather at readily accessible locations that appeared to support greater diversity.

Each sample was carefully wrapped in tissue paper and placed in a paper envelope. Samples remained in this condition until their accession into CHR (Allan Herbarium, Manaaki Whenua/Landcare Research, Lincoln, New Zealand; Table S1) in April 2018. Detailed examination was then made of all samples, leading to identifications of lichens (D.O. Øvstedal) and mosses (R. Ochyra).

Results

Nunataks from which fewer samples were collected yielded fewer taxa (Tables II & S1). Six nunataks from which 14 or fewer samples were taken had eight or fewer taxa. Four nunataks with 18–29 samples had 10–15 taxa, whilst the remaining seven nunataks with 32–53 samples had 16–26 taxa. This last group of nunataks included just one location, Scott Nunataks, in Alexandra Mountains. Five of the 10 nunataks with 15 or fewer taxa were in Alexandra Mountains. This is reflected in the overall comparison of Alexandra Mountains (122 samples and 30 taxa from 6 nunataks) with Rockefeller Mountains (296 samples and 49 taxa from 15 nunataks).

Lichens

A total of 43 taxa was recognized. Thirty were assigned to species and one to a variety. Four were compared to species (using 'cf.' in Table II), but their identities require confirmation. Eight were assigned only to genera. Six samples remained undetermined as specimens were sterile.

Of the 23 taxa found at both Rockefeller and Alexandra Mountains, the most widespread species were *Usnea sphacelata* and *Pseudephebe minuscula*, which were found at 14 nunataks, *Umbilicaria decussata* at 13, *Candelariella flava* at 10 and *Physcia caesia* and *Lecanora physciella* var. *sorediata* both at nine. A single new species, *Amandinea clearyi* (Elix *et al*. 2020), occurred at three and four nunataks, respectively, at Alexandra and Rockefeller Mountains.

A total of 42 taxa was found at Rockefeller Mountains, and 17 of these were found only there. The three most prominent of the latter were *Acarospora gwynnii* (20 samples from 5 nunataks), *Rinodina olivaceobrunnea* (11 samples from 6 nunataks) and *Xanthoria elegans* (17 samples from 3 nunataks). Mount Nilsen, with 24 taxa, was the richest location, whilst Fokker Rocks was the only nunatak at which lichens were not found.

Alexandra Mountains yielded 29 taxa, and four of these were found only there, but in just single samples. Scott Nunataks with 18 taxa was the richest location.

https://doi.org/10.1017/S0954102022000396 Published online by Cambridge University Press

Table I. Sample locations on Edward VII Peninsula.

Location	Code in Table II	Latitude	Longitude	Elevation (m above sea level)	Herbarium specimens CHR647+ …
Alexandra Mountains					
Scott Nunataks	SN	77°12.44'S	154°33.94'W	703	701–736, 853–858
Mount Swadener	SW	77°16.48'S	153°45.08'W	518	748–761
Bowman Peak	BO	77°28.39'S	153°31.24'W	570	737–739
Clark Peak	CL	77°31.48'S	154°11.56'W	646	791–816
Mount Josephine	JO	77°31.68'S	153°06.84'W	762	740–747
La Gorce Peak	LA	77°37.53'S	153°42.09'W	1174	762–790
Rockefeller Mountains					
Drummond Peak	DR	77°51.32'S	153°58.40'W	786	481–512
Mount Frazier	FJF	77°52.60'S	155°24.71'W	820	693–700, 834–836
Mount Jackling	FJF	77°54.01'S	155°19.15'W	~850	693–700, 834–836
Mount Fitzsimmons	FJF	77°54.28'S	155°16.36'W	876	693–700, 834–836
Strider Rock	ST	78°02.02'S	155°26.45'W	~650	675–692
Mount Paterson	PA	78°02.56'S	155°00.00'W	690	513–543, 839–841
Mount Nilsen	NI	78°03.36'S	155°19.46'W	702	578–628, 851–852
Mount Schlossbach	SC	78°03.77'S	155°12.97'W	~650	472–480
Fokker Rocks	FO	78°04.44'S	155°10.38'W	~450	837–838
Breckinridge Peak	BR	78°04.84'S	155°27.24'W	570	629–674, 817–820
Mount Franklin	FN	78°05.38'S	155°18.49'W	450	544–577
Washington Ridge	WA	78°06.59'S	155°13.70'W	430	441–462, 821–833
Gould Peak	GTB	78°07.80'S	155°39.78'W	440	463–471, 842–850
Tennant Peak	GTB	78°09.15'S	155°45.65'W	419	463–471, 842–850
Mount Butler	GTB	78°09.15'S	155°47.93'W	~400	463–471, 842–850

Latitudes, longitudes and elevations taken from United States Geological Survey (1972). See also Figs S1–S19.

Twenty-four taxa were particularly infrequent and occurred at only one to three nunataks. Four were found only at Alexandra Mountains and 15 only at Rockefeller Mountains. Five occurred at both.

Fungus

At both mountain ranges, black crusts covering the soil were found to be dominated by cyanobacteria, amongst which a fungus was closely associated with *Gloeocapsa* sp. This has been established as a new species, *Sclerococcum gloeocapsae* (Øvstedal *et al.* 2021). It was identified from four nunataks, and similar but unidentified black crusts were more widespread.

Mosses

Mosses comprised six species and one variety from five genera. *Orthotrichum* sp. is still under investigation, and a full description will be published elsewhere. It is considered to be a new species. All seven taxa occurred at Rockefeller Mountains, whereas only *Schistidium antarctici* was found in Alexandra Mountains at Scott Nunataks. This species was also the most widely distributed, at a total of six nunataks, and the most frequently sampled. *Grimmia plagiopodia* and *Bryum argenteum* var. *argenteum* both occurred at three nunataks, whereas the remaining four taxa were found at just a single location.

Of the total of eight nunataks at which mosses were found, five of these supported a single species. Mount Nilsen had two species, Washington Ridge had three species, including both varieties of *B. argenteum*, whilst Paterson Ridge had the richest flora of five species. Although the three samples containing *Orthotrichum* sp. were from a group of three adjacent nunataks (Mounts Frazier, Jackling and Fitzsimmons) that were not distinguished on sample labels, field notes indicated that this species was collected only at Mount Fitzsimmons (Fig. S13).

Discussion

Lichens

Of the 23 lichen taxa identified in a screening of a small subset of samples from Edward VII Peninsula (Broady 1989), six were not found in the samples reported here. These are: cf. *Buellia soredians* Filson, *Caloplaca athallina* Darb., *Pleopsidium chlorophanum* (Wahlenb.) Zopf (originally listed as *Biatorella cerebriformis* Filson), *Pseudephebe* aff. *pubescens* (L.) Brodo & Hawksw., *Rhizocarpon geographicum* f. *foliosum* (Filson) (formal recombination yet to be made; originally listed as *R. flavum* f. *subfoliosum* Filson) and *Rhizoplaca melanophthalma* (Ram.) Lwck. & Poelt. No record was kept of their source nunataks, so their distribution across the region is unknown. Together with the 44 taxa found

https://doi.org/10.1017/S0954102022000396 Published online by Cambridge University Press

Table II. The distribution of lichens, fungi and mosses amongst the nunataks of Alexandra Mountains and Rockefeller Mountains, Edward VII Peninsula, Antarctica.

Species and authority	All nunataks	Alexandra Mountains							Rockefeller Mountains											
		All nunataks	SN	SW	BO	CL	JO	LA	All nunataks	DR	FJF	ST	PA	NI	SC	FO	BR	FN	WA	GTB
Lichens																				
Acarospora gwynnii C.W. Dodge & Rudolph	5/20[a]	0/0							5/20	1[b]		5	4	5			5			
Amandinea clearyi Elix & Øvstedal	7/15	3/8	1			2		5	4/7	2			1				2	2		
Bacidia coprodes Körb.	4/7	1/3				3			3/4	2				1	1					
Buellia frigida Darb.	2/2	0/0							2/2						1			1		
Buellia subfrigida May. Inoue	3/3	1/1				1			2/2	1					1					
Buellia spp. unidentified	10/27	5/10	3	1		4	1	1	5/17	5				6	1		2	3		
Caloplaca s. lat. spp. unidentified	9/19	2/3	1					2	7/16	5	1	1	3	2			3		1	
Candelariella flava (C.W. Dodge & Baker) Castello & Nimis	10/42	2/9	5					4	8/33	3		2	9	3			4	1	9	2
Lecanora epibryon (Ach.) Ach.	3/5	1/2	2						2/3				2						1	
Lecanora mawsonii C.W. Dodge	1/1	0/0							1/1	1										
Lecanora physciella (Darb.) Hertel	2/3	1/1				1			1/2					2						
Lecanora physciella var. *sorediata* Øvstedal	9/18	4/10	2	3		4	1		5/8	1			1	1	1			4		
Lecanora pseudephebae Øvstedal	5/6	2/2				1		1	3/4	1				1			2			
Lecanora usneicola Etayo	1/1	0/0							1/1	1										
Lecanora cf. *geophila* (Th. Fr.) Poelt	1/1	1/1	1						0/0											
Lecanora cf. *griseosorediata* Øvstedal	1/1	1/1					1		0/0											
Lecanora cf. *sverdrupiana* Øvstedal	1/1	1/1						1	0/0											
Lecanora spp. unidentified	6/8	1/1						1	5/7	1		2	2				1		1	
Lecidea andersonii Filson	2/3	1/1	1						1/2					2						
Lecidea cf. *cancriformis* C.W. Dodge & G.E. Baker	1/1	0/0							1/1					1						
Lecidea spp. unidentified	2/2	0/0							2/2	1	1									
Lecidella spp. unidentified	4/5	1/1	1						3/4		1	2		1						
Lepraria spp. unidentified	8/21	1/2	2						7/19	1	2		1	8	1		5			1
Mycobilimbia sp.	1/1	1/1	1						0/0											
Physcia caesia (Hoffm.) Fürnr.	9/28	2/2	1					1	7/26	8	4		7				1	1	3	2
Physconia muscigena (Ach.) Poelt	1/1	0/0							1/1				1							
Polysporina frigida Kantvilas & Seppelt	1/1	0/0							1/1											1
Pseudephebe minuscula (Nyl. ex Arnold) Brodo & D. Hawksw.	14/56	6/29	4	7	1	12	1	4	8/27	2		2	2	5	2		7	4		3
Rhizocarpon adarense (Darb.) I.M. Lamb	2/5	0/0							2/5					2			3			
Rhizocarpon geographicum (L.) DC.	2/3	0/0							2/3					2				1		
Rhizocarpon nidificum (Hue) Darb.	1/1	0/0							1/1					1						
Rhizocarpon sp.	3/4	0/0							3/4					2			1	1		
Rhizoplaca aspidophora (Vain.) Redón	7/14	2/4	3					1	5/10	1		1	1				2		5	
Rinodina olivaceobrunnea C.W. Dodge & G.E. Baker	6/11	0/0							6/11		4		2	1				1	1	2
Tephromela disciformis Øvstedal	2/2	0/0							2/2								1			1
Umbilicaria antarctica Frey & I.M. Lamb	1/1	0/0							1/1								1			
Umbilicaria aprina Nyl.	4/15	1/3		3					3/12			2		2			8			
Umbilicaria decussata (Vill.) Zahlbr.	13/41	4/10	1	2		3		4	9/31	1		3	4	7	1		7	4	3	1
Umbilicaria nylanderiana (Zahlbr.) H. Magn.	9/20	4/10	4	2			1	3	5/10	1		2	3				2		2	
Usnea antarctica Du Rietz	2/2	0/0							2/2					1				1		
Usnea sphacelata R. Br.	14/59	5/19	3	3		7	4	2	9/40	10		2	4	6	1		8	1	6	2
Xanthomendoza borealis (R. Sant. & Poelt) Søchting, Kärnefelt & S. Kondratyuk	3/7	1/1						1	2/6				2						4	
Xanthoria elegans (Link) Th. Fr.	3/17	0/0							3/17				9					6	2	

Sterile lichens undetermined	5/6	1/1	1						4/5			1	1	1			2			
Fungi																				
Sclerococcum gloeocapsae Øvstedal, Broady & Fryday	4/10	1/1						1	3/9			1		1				7		
Mosses																				
Bryum argenteum var. *argenteum* Hedw.	3/3	0/0							3/3				1	1					1	
Bryum argenteum var. *muticum* Brid.	1/7	0/0							1/7										7	
Bryum pseudotriquetrum (Hedw.) P.Gaertn., B.Mey. & Scherb.	1/1	0/0							1/1				1							
Grimmia plagiopodia Hedw.	3/6	0/0							3/6				1	2					3	
Orthotrichum sp.	1/3	0/0							1/3		3									
Schistidium antarctici (Card.) L. Savic. & Smirn.	6/25	1/6	6						5/19				1			2	4		3	9
Syntrichia sarconeurum (Hook.f. & Wilson) Ochyra & R.H.Zander	1/1	0/0							1/1				1							
Number of taxa (lichens + fungi/mosses)	45/7	28/1	18/1	7/0	1/0	10/0	6/0	15/0	41/7	20/0	6/1	13/0	19/5	24/2	9/0	0/1	20/1	15/0	12/4	9/1
Number of samples (lichens + fungi/mosses)	337/46	94/6	25/6	12/0	1/0	25/0	8/0	23/0	243/40	34/0	8/3	15/0	31/5	51/3	7/0	0/2	41/4	30/0	18/14	8/9

[a] Numbers are nunataks/samples.

[b] Numbers are samples.

Alexandra Mountains: BO = Bowman Peak, CL = Clark Peak, JO = Mount Josephine, LA = La Gorce Peak, SN = Scott Nunataks, SW = Mount Swadener.

Rockefeller Mountains: BR = Breckinridge Peak, DR = Drummond Peak, FJF = Mounts Frazier, Jackling and Fitzsimmons, FN = Mount Franklin, FO = Fokker Rocks, GTB = Gould Peak, Mounts Tenant and Butler, NI = Mount Nilsen, PA = Mount Paterson, SC = Mount Schlossbach, ST = Strider Rock, WA = Washington Ridge.

the samples examined in this survey, they bring the total number of taxa found in this region to 50. This number would be greater if identifications were made of material currently identified only to the generic level (small species of *Buellia*, *Caloplaca* s. lat., *Lecanora*, *Lecidea*, *Lecidella* and *Lepraria*).

Of these 50 taxa, 40 have been recorded previously from the Continental Antarctic zone. Only three of these 40 species are endemic to this zone, whilst the remaining 37 also occur on the Antarctic Peninsula or on islands of the Maritime Antarctic zone (Øvstedal & Lewis Smith 2001, table 8). Of the three endemics, two were listed by Øvstedal & Lewis Smith (2001; *Buellia soredians* and *Lecanora mawsonii*) and one, *Polysporina frigida*, was described by Kantvilas & Seppelt (2006). The new species *A. clearyi* (Elix *et al*. 2020) brings the total number of endemics to four. The remaining nine taxa are new records for the Continental Antarctic zone, having previously been found on the Antarctic Peninsula or on islands of the Maritime Antarctic zone (Øvstedal & Lewis Smith 2001, table 8). These are: *Lecanora epibryon*, *Lecanora pseudephebae*, *Lecanora usneicola*, *Lecanora* cf. *griseosorediata*, *Pseudephebe* aff. *pubescens*, *Rhizocarpon nidificum*, *Rhizoplaca aspidophora*, *Tephromela disciformis* and *Umbilicaria nylanderiana*.

The total number of lichen taxa in the Continental Antarctic zone is 88 according to Øvstedal & Lewis Smith (2001, table 8). The 39 listed there that are now known to occur at Edward VII Peninsula is a substantial proportion (44%) of that total. Furthermore, the 10 additional taxa found in this survey that are first records for the Continental Antarctic zone increase the total for that zone to 98. However, the four taxa from Edward VII Peninsula that are Continental Antarctic zone endemics is a small proportion (9%) of their total of 44 endemics (Øvstedal & Lewis Smith 2001, table 9). This indicates that the lichen flora of Edward VII Peninsula has a fairly strong relationship with that of the Antarctic Peninsula and islands of the Maritime Antarctic.

The Mount Kyffin region (~84°S, 172°E) in Queen Maud Mountains has also been found to support a diverse lichen flora of over 30 species, of which six have been reported from close to or on the Antarctic Peninsula (Green *et al*. 2011). Only two of these six species, *Rhizocarpon adarense* and *Rhizocarpon nidificum*, were collected on Edward VII Peninsula.

Mosses

Of the five moss species identified in the earlier subset of samples (Broady 1989), all have been found in the present samples. However, *Grimmia lawiana* J.H. Willis is now regarded as a misidentification of *S. antarctici*, and *Sarconeurum glaciale* (Müll.Hal.) Cardot & Bryhn is a synonym of *Syntrichia sarconeurum*. Additional identifications in the present samples are *B. argenteum* var. *muticum*, *G. plagiopodia* and *Orthotrichum* sp.

A species that has not been found in the present samples but is previously known from Edward VII Peninsula is *Schistidium urnulaceum* (Müll.Hal.) B.G.Bell. This was found in a sample collected from Tennant Peak, Rockefeller Mountains, by the United States Antarctic Service Expedition of 1939–1941 (Ochyra *et al*. 2008, p. 250) and identified as *Grimmia antarctici* var. *pilifera* by Bartram (1957), but this is now a synonym of *S. urnulaceum* (Ochyra *et al*. 2008, p. 247). It is known in Continental Antarctica only from Marie Byrd Land, whilst also occurring in the northern Maritime Antarctic zone and being widely distributed on South Georgia in the Subantarctic zone. This brings the total known taxa of mosses on Edward VII Peninsula to seven species and one variety.

Orthotrichum sp. is particularly interesting as it is the first record for this genus in the Continental Antarctic zone as defined by Ochyra *et al*. (2008, pp. 2–4). The genus is represented in the northern Maritime Antarctic zone by *Orthotrichum rupestre* Schwägr. (Ochyra *et al.* 2008, p. 414), where it occurs on the west coast of the Antarctic Peninsula at altitudes < 100 m. The present specimens were found at a considerably higher elevation of ~876 m.

Two species, *S. antarctici* and *S. sarconeurum*, are Antarctic endemics. *S. antarctici* has a wide distribution (Ochyra *et al*. 2008, p. 255). It has been recorded previously in Rockefeller Mountains by Bartram (1938, 1957) on Washington Ridge, Mount Paterson, Tennant Peak and a 'Northern Group' of nunataks (as *G. antarctici* and *G. antarctici* var. *percompacta*). In this study, it was the most widely distributed species, being at six nunataks, including three new locations: Breckinridge Peak, Tennant Peak and Scott Nunataks, the latter being its first record in Alexandra Mountains. *S. sarconeurum* is also widespread (Ochyra *et al.* 2008, p. 381) and has previously been found in Rockefeller Mountains at Mount Paterson (Bartram 1957, as *S. glaciale*). This was also its only location in the present collections.

Two species, *Bryum pseudotriquetrum* and *G. plagiopodia*, are predominantly bipolar (Ochyra *et al*. 2008). *B. pseudotriquetrum* is one of the most widespread and common Antarctic mosses, especially in Victoria Land (Ochyra *et al*. 2008, p. 480). In contrast, in the present collections it was found only in a single sample from Mount Paterson. This is a first record for Edward VII Peninsula. Although its occurrence on Edward VII Peninsula was noted by Ochyra *et al*. (2008, pp. 480–481), this was an error. Its only other record in Marie Byrd Land is from Ford Ranges as *Bryum antarcticum* Hook. f. & Wils. (Bartram 1938). *G. plagiopodia* is scattered throughout Antarctica but in general is very rare (Ochyra *et al*. 2008, p. 274).

https://doi.org/10.1017/S0954102022000396 Published online by Cambridge University Press

In Marie Byrd Land, it has previously been found at a single location in Ford Ranges (Bartram 1957). Its occurrences on three nunataks in Rockefeller Mountains are the first records of this species from Edward VII Peninsula.

B. argenteum var. *argenteum* is ubiquitous worldwide and is widely distributed but scattered and infrequent in Antarctica (Ochyra *et al.* 2008, p. 458). In Marie Byrd Land, it has previously been recorded, as *Bryum siplei* Bartr., from two locations in Rockefeller Mountains - Washington Ridge (Bartram 1938) and Mount Paterson (Bartram 1957) - and at one location in Ford Ranges (Bartram 1938). In the present collections, the only additional location was in Rockefeller Mountains at Mount Nilsen, and its presence was confirmed at Washington Ridge and Mount Paterson. *B. argenteum* var. *muticum* is also probably cosmopolitan and has an Antarctic distribution that is very similar to the type variety (Ochyra *et al.* 2008, p. 462). Its presence on Washington Ridge is the first record of this species for Marie Byrd Land, and its occurrence in seven samples suggests a wide distribution of this species at this single nunatak.

Comparison of the flora with those of locations in southern Victoria Land at similar latitudes

A comparison of the flora of Edward VII Peninsula can be made with that of Botany Bay, which lies at a similar latitude (77°00'S, 162°33'E,) in Granite Harbour, southern Victoria Land. This location has been described as 'extremely rich botanically for such a high latitude' and as 'one of the richest sites in the whole of continental Antarctica' (Seppelt *et al.* 2010). It supports > 30 lichen, nine moss and one liverwort species. The mosses include all seven species that are found in the whole of southern Victoria Land. It has been designated as Antarctic Specially Protected Area 154 largely due to its botanical value (Antarctic Treaty Secretariat 2019). Edward VII Peninsula has a species richness that is greater in lichens, with > 50 species, and similar in mosses, with seven species and one variety. The two nunataks with the greatest species richness, Mount Nilsen and Mount Paterson in Rockefeller Mountains, taken together have five moss and > 32 lichen species. This comparison suggests that the region could also be termed botanically rich.

The rich vegetation at Botany Bay is attributed to the very favourable climate, excellent water supply and nutrient input from birds (Seppelt *et al.* 2010). The climate at Edward VII Peninsula is undoubtedly more severe than at Botany Bay because of the higher altitude and the great extent of the ice fields surrounding the nunataks. However, several nunataks must be well-supplied with nutrients from nesting birds, especially Mount Paterson with its large snow petrel and Antarctic petrel colonies and associated skuas (Broady *et al.* 1989). In addition, melt from frequent episodes of snowdrift and snowfall during summer would provide a reliable but not abundant water supply.

A comparison of species occurrences at the two locations shows some considerable differences. There are only 11 lichen species in common. A notable absence from Botany Bay is the lichen *Usnea*, but it does occur at Edward VII Peninsula with *U. sphacelata* at 14 nunataks and *U. antarctica* at two of these. However, both of these species are found at other locations in southern Victoria Land. Four of the nine moss species at Botany Bay are absent from Edward VII Peninsula: *Bryoerythrophyllum recurvirostrum* (Hedw.) P.C.Chen, *Ceratodon purpureus* (Hedw.) Brid., *Didymodon brachyphyllus* (Sull.) R.H.Zander and *Hennediella heimii* (Hedw.) R.H.Zander. Just one of these four species, *D. brachyphyllus*, is recorded from Marie Byrd Land in Ford Ranges as *Barbula byrdii* Bartram (Ochyra *et al.* 2008, p. 339).

This comparison can be extended to include the vegetation of Kar Plateau (Seppelt *et al.* 1995) which is an ~600 m-altitude felsenmeer just 8 km north of Botany Bay at 76°56'S, 162°20'E and forming the northern arm of Granite Harbour. Its climate is probably more similar to Edward VII Peninsula than that of Botany Bay. It supports > 25 species of lichen and five moss species. All the mosses occur at Botany Bay but ~10 of the lichens do not, including *U. antarctica*. Taken together, Botany Bay and Kar Plateau have > 40 lichen species with only 10 fully identified species also found at Edward VII Peninsula. Edward VII Peninsula is more species rich in lichens but mostly comprises different species from those at Botany Bay and Kar Plateau.

Has the flora recolonized nunataks since the Last Glacial Maximum?

The first description of the geology of Edward VII Peninsula briefly considered the erosional features of the nunataks and concluded that 'the present forms are due to the glacial erosion' (Wade 1945, p. 72). Further evidence that this might have been the case is reported in a study of weathering and erosion in the Sarnoff and Allegheny Mountains, Ford Ranges, Marie Byrd Land (Sugden *et al.* 2005). These mountains lie ~300 km east of Edward VII Peninsula and are generally somewhat higher (700–1100 m) than the nunataks of Edward VII Peninsula (~400–1174 m) but of similar maximum elevation. All of the summits in the study area were considered to have been ice-covered during the Last Glacial Maximum (LGM) prior to 10,400 years BP, perhaps by a few hundred metres of ice, and to have been gradually uncovered during the Holocene. The duration of recent exposure was suggested to range from < 2000 years near the present ice margin to 10 400 years at the 810 m summit of Mount Rea.

https://doi.org/10.1017/S0954102022000396 Published online by Cambridge University Press

Assuming that the nunataks of Edward VII Peninsula were similarly ice-covered during the LGM, then mosses and lichens must either have survived below the ice cover or have recolonized through dispersal from elsewhere as rock surfaces gradually emerged. The survival of Antarctic terrestrial biota through the LGM, either in ice-free refugia or by cryptobiosis in ice or permafrost, has been discussed by Convey *et al.* (2020). They provided an overview of the evidence that mosses survive ice burial for periods of centuries to millennia but concluded that it is unknown whether their survival would be possible through entire glacial cycles. Potential ice-free refugia include Victoria Land dry valleys, mountain ranges of Victoria Land at altitudes above the 'high stand' of ice estimated at the LGM and those in the Antarctic Peninsula and off-shore islands. Therefore, considerable ambiguity remains with regard to the recent origins of the flora of Edward VII Peninsula. The application of future improvements in molecular biological dating techniques may allow for this to be clarified.

Conclusions

The moss and lichen flora of Edward VII Peninsula is species rich. A major cause of this could be a favourable moisture supply in summer together with the presence of sites that range from being strongly enriched in nutrients supplied by nesting birds to being relatively unenriched. These lichens include a large proportion of species also known from the Antarctic Peninsula and Maritime Antarctic islands, whilst those endemic to the Continental Antarctic zone are relatively few. The occurrence of a species of moss, *S. urnulaceum*, known only from Marie Byrd Land, the Antarctic Peninsula and South Georgia, strengthens this connection with less climatically severe regions. Of great interest is the first record of a possible new species of *Orthotrichum* in the Continental Antarctic zone. Of the remaining five moss species, two are new records for Edward VII Peninsula, but all five occur elsewhere in Marie Byrd Land as well as having wide distributions in Continental Antarctica and on the Antarctic Peninsula and Maritime Antarctic islands. Because the opportunistic collection of samples was of limited scope at several nunataks, it is possible that additional lichen and moss species could be found through more thorough collections in the future. In addition, the number of lichen species would be increased by the detailed examination of specimens of six genera for which species are presently unidentified.

Acknowledgements

The staff at the Allan Herbarium (CHR), Manaaki Whenua - Landcare Research, Lincoln, New Zealand, are thanked for their indispensable help. PAB thanks Antarctica New Zealand and the US National Science Foundation for logistical support and Peter Cleary, Chris Adams and Steven Weaver for companionship in the field. Two anonymous reviewers provided helpful comments.

Financial support

Fieldwork was supported by Antarctica New Zealand and was performed when PAB was employed by the University of Canterbury.

Author contributions

PAB collected the specimens. DOØ identified lichens. RO identified mosses. The manuscript was written with significant input from all authors.

Supplemental material

Nineteen supplemental figures and a supplemental table will be found at https://doi.org/10.1017/S0954102022000396.

References

Adams, C.J., Seward, D. & Weaver, S.D. 1995. Geochronology of Cretaceous granites and metasedimentary basement on Edward VII Peninsula, Marie Byrd Land, West Antarctica. *Antarctic Science*, **7**, 265–277.

Adams, C.J., Broady, P.A., Cleary, P.J. & Weaver, S.J. 1989. Geological and biological expedition to Edward VII Peninsula, Marie Byrd Land, West Antarctica - 1987/88: field observations and initial results. *New Zealand Antarctic Record*, **9**, 4–33.

Amundsen, R. 1912. *The South Pole*. London: John Murray, 449 pp.

Antarctic Treaty Secretariat. 2019. Status of Antarctic Specially Protected Area and Antarctic Specially Managed Area management plans. Retrieved from https://documents.ats.aq/ATCM42/WW/atcm42_ww006_e.pdf

Bartram, E.B. 1938. Botany of Second Byrd Antarctic Expedition III. Mosses. *Annals of the Missouri Botanical Garden*, **25**, 719–724.

Bartram, E.B. 1957. Mosses from the United States Antarctic Service Expedition, 1940–41. *The Bryologist*, **60**, 139–143.

Broady, P.A. 1989. Survey of algae and other terrestrial biota at Edward VII Peninsula, Marie Byrd Land. *Antarctic Science*, **1**, 215–224.

Broady, P.A., Adams, C.J., Cleary, P.J. & Weaver, S.D. 1989. Ornithological observations at Edward VII Peninsula, Antarctica in 1987–88. *Notornis*, **36**, 53–61.

Convey, P.C., Biersma, E.M., Casanova-Katny, A. & Maturana, C.S. 2020. Refuges of Antarctic diversity. *In* Oliva, M. & Ruiz-Fernández, J. *eds. Past Antarctica*. Burlington, MA: Academic Press, 181–200.

Dagnell, L. & Shibata, H. (translators) 2011. *The Japanese South Polar Expedition 1910–12. A record of Antarctica*. Huntingdon: Bluntisham Books, 414 pp.

Dodge, C.W. 1973. *Lichen flora of the Antarctic continent and adjacent islands*. Canaan, NH: Phoenix Publishing, 399 pp.

Dodge, C.W. & Baker, G.E. 1938. The Second Byrd Antarctic Expedition - botany. II. Lichens and lichen parasites. *Annals of the Missouri Botanic Garden*, **25**, 515–718.

Elix, J.A., Øvstedal, D.O. & Broady, P.A. 2020. A new sorediate species of *Amandinea* (Caliciaceae, Ascomycota) from Antarctica. *Australasian Lichenology*, **86**, 70–73.

Gould, L.M. 1931. *Cold: the record of an Antarctic sledge journey.* New York: Brewer, Warren & Putman, 275 pp.

Green, T.G.A., Sancho, L.G., Türk, R., Seppelt, R.D. & Hogg, L.D. 2011. High diversity of lichens at 84°S, Queen Maud Mountains, suggests preglacial survival of species in the Ross Sea region, Antarctica. *Polar Biology*, **34**, 10.1007/s00300-011-0982-5.

Kantvilas, G. & Seppelt, R.D. 2006. *Polysporina frigida* sp. nov. from Antarctica. *The Lichenologist*, **38**, 10.1017/S0024282906005640.

Ochyra, R., Lewis Smith, R.I. & Bednarek-Ochyra, H. 2008. *The illustrated moss flora of Antarctica*. Cambridge: Cambridge University Press, 704 pp.

Øvstedal, D.O. & Lewis Smith, R.I. 2001. *Lichens of Antarctica and South Georgia*. Cambridge: Cambridge University Press, 411 pp.

Øvstedal, D.O., Broady, P.A. & Fryday, A.M. 2021. A new *Sclerococcum* (Dactylosporaceae, Ascomycota) on *Gloeocapsa* from Antarctica. *Australasian Lichenology*, **88**, 40–44.

Perkins, J.E. 1945. Biology at Little America III, the West Base of the United States Antarctic Service Expedition 1939–41. *Proceedings of the American Philosophical Society*, **89**, 270–284.

Rudolph, E.D. 1967. Biological survey of Marie Byrd Land. *Antarctic Journal of the United States*, **2**, 96–97.

Seppelt, R.D., Green, T.G.A. & Schroeter, B. 1995. Lichens and mosses from the Kar Plateau, southern Victoria Land, Antarctica. *New Zealand Journal of Botany*, **33**, 10.1080/0028825X.1995.10410484.

Seppelt, R.D., Türk, R. & Green, T.G.A., Moser, G., Pannewitz, S., Sancho, L.G. & Schroeter, B. 2010. Lichen and moss communities of Botany Bay, Granite Harbour, Ross Sea, Antarctica. *Antarctic Science*, **22**, 10.1017/S0954102010000568.

Siple, P.A. 1938. The Second Byrd Antarctic Expedition - botany. *Annals of the Missouri Botanic Garden*, **25**, 467–514.

Sugden, D.E., Balco, G., Cowdery, S.G., Stone, J.O. & Sass, L.C. III 2005. Selective glacial erosion and weathering zones in the coastal mountains of Marie Byrd Land, Antarctica. *Geomorphology*, **67**, 10.1016/j.geomorph.2004.10.007.

United States Geological Survey. 1972. *Alexandra Mountains, Antarctica*. 1:250 000. Washington, DC: United States Department of the Interior, Geological Survey.

Wade, F.A. 1945. The geology of the Rockefeller Mountains, King Edward VII Land, Antarctica. *Proceedings of the American Philosophical Society*, **98**, 67–77.