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A PRELIMINARY INVESTIGATION OF THE DIVERSITY, SURVIVABILITY AND DISPERSAL OF ALGAE INTRODUCED INTO ANTARCTICA BY HUMAN ACTIVITY

Paul A. BROADY[1] and Robert A. SMITH[2]

[1]*Department of Plant and Microbial Sciences, University of Canterbury, Christchurch, New Zealand*
[2]*National Institute of Water and Atmosphere, Kyle Street, Riccarton, Christchurch, New Zealand*

Abstract: Human activity was found to be an effective vector for the dispersal of microalgae to the Ross Sea regions of Antarctica. A total of 50 taxa, mostly typical soil algae, were identified as potential colonizers. Sample material included dust on equipment and boots of expeditioners taken prior to boarding aircraft bound for Antarctica, and soil adherrent to fresh vegetables imported into Scott Base, Ross Island. 10 taxa were from genera unrecorded in the Ross Sea regions. *Cylindrospermum* (Cyanophyta) and *Eustigmatos* (Eustigmatophyta) are relatively easily recognised and their spread could be monitored if they became established in Antarctic habitats. However, there was no evidence of the establishment of any exogenous algae even in highly perturbed habitats close to Scott Base. Airborne dispersal within Antarctica was found to disperse algal propagules in the vicinity of Scott Base, although numbers were very low, being two orders of magnitude lower than those found in New Zealand. The ability of indigenous Antarctic algae and exogenous potential colonizers to survive freeze-thaw cycles, high salinity and desiccation was investigated in laboratory experiments. In general, strains isolated from dust on boots and equipment and from New Zealand air showed high survivability, as did the indigenous Antarctic strains. In contrast, strains isolated from soil on fresh vegetables imported into Antarctica had low survival similar to those isolated from a typical moist New Zealand garden soil. Suggestions are provided on how these preliminary investigations can be extended and improved.

1. Introduction

There is considerable circumstantial evidence that Antarctica receives a steady supply of microbial and bryophyte diaspores from land masses to the north (WALTON, 1990). The principle means of dispersal appears to be by air currents but also migrating birds might be effective vectors (SCHLICHTING *et al.*, 1978). From the moment that humans first set foot on the Continent in 1895 it is likely that we have also been vectors for the dispersal of alien microorganisms to Antarctica. This was demonstrated by CAMERON *et al.* (1977) for bacteria and fungi in southern Victoria Land.

Despite the increase in human presence on the Continent it should still be possible to compare impacted and "pristine" areas in order to recognise alien introductions (WALTON, 1990). The need for investigations focussing on the detection and monitoring of exogenous organisms was noted by RUDOLPH and

BENNINGHOF (1977) but since then there has been little progress (VINCENT, 1988). It is intended that a major focus on these problems by the international BIOTAS programme (Biological Investigations of Terrestrial Antarctic Systems) will help remedy this situation (SMITH and WYNN-WILLIAMS, 1992).

Algae are the most widespread and abundant photosynthetic life in terrestrial and aquatic Antarctic ecosystems. It is therefore important to assess the possibility of exogenous algae being dispersed to, and establishing in, these habitats.

Worldwide there are increasing numbers of examples of algae being dispersed to new areas by humans and then growing to nuisance proportions. Two recent examples are the dispersal of toxic marine dinoflagellates in the ballast water of ships (HALLEGRAEFF *et al.*, 1988), and the introduction of the freshwater alga "water-net" (*Hydrodictyon reticulatum*) into New Zealand lakes (COFFEY and MILLER, 1988). Likewise, it is possible that humans could be the vector for the dispersal of algae to Antarctica which might then establish vigorous populations and degrade the scientific value of formerly pristine habitats, as well as change unique communities of great conservation value.

The aims of this investigation were to, i) obtain preliminary data on the diversity, and means of dispersal, of algae being transported to Antarctica by humans, ii) investigate whether any exogenous algae had established populations in the Antarctic environment, iii) examine the means of dispersal of algae within Antarctica and iv) compare the survivability of exogenous and indigenous algae in laboratory experiments, following exposure to extreme conditions similar to those experienced by Antarctic microorganisms.

2. Materials and Methods

2.1. Detection of potential Antarctic colonizers in New Zealand

Christchurch in the South Island, New Zealand, is the departure point for aircraft flying to Ross Island, Antarctica with equipment and personnel of the United States Antarctic Program and of the New Zealand Antarctic Programme. Samples were taken at, and in the vicinity of, Christchurch International Airport for the investigation of diaspores of algae with high potential for transport to Antarctica on board the aircraft.

Sterile cotton wool swabs were used to remove dust from the surfaces of equipment and crates which were to be taken to Antarctica from the stores of the New Zealand Antarctic Programme. Also, swabs were made from shelving and the floor. Each swab was streaked over the surface of an agarised, mineral salts medium (Bold's basal medium, (BBM; NICHOLS, 1973) with added silicon (BBMS) at 0.0028 g l^{-1} solidified with 1.5% w/v agar; addition of silicon increased the pH of the medium from 6.7 to 6.8) and the cultures were incubated for three weeks at 20°C illuminated by cool-white fluorescent tubes (approx. 100 μE m^{-2} s^{-1}) on a 16:8 h light:dark cycle. Following incubation colonies were isolated and identified.

The same technique as above was used to sample and grow algae from the boots of expeditioners as they boarded an aircraft before departure for Antarc-

tica. Expeditioners change into their Antarctic gear before boarding and it was assumed that a proportion of the adherrent algae would remain on arrival.

Airborne diaspores would have opportunity to adhere to clothing and equipment and to enter aircraft prior to departure. Samples of airborne diaspores were collected on three occasions using both a Rotorod and a Burkard high throughput "Jet" spore sampler (see WYNN-WILLIAMS, 1992, for descriptions of the use of these). The "Jet" spore sampler was used to collect particles into sterile 200 m*l* polycarbonate bottles. Appropriate controls were used on all occasions in order to test for contamination. On return to the laboratory the silicone oil-coated rods from the Rotorod were streaked over agarised BBMS medium. Particles collected by the "Jet" spore sampler were suspended in sterile liquid BBMS. The suspension was filtered through a 0.45 μm membrane filter which was then placed on the surface of agarised BBMS medium. Incubation was as described above.

2.2. Detection of exogenous algae on fresh food at Scott Base

During summer, fresh vegetables are transported to Scott Base, Ross Island from New Zealand. Traces of soil were found adhering to their surfaces. Sterile, moistened portions of glass-fibre filter paper were used to swab the surfaces of lettuces and potatoes. The swabs were then smeared over agarised BBMS medium and incubated as described in 2.1. Algae were isolated and identified.

2.3. Investigation of establishment of exogenous algae in the Antarctic environment

Algae were identified from soils and aquatic habitats amongst, and in the immediate vicinity of, the huts of Scott Base in an attempt to detect exogenous algae which could have established active populations. Material examined included dry, sandy soils lacking any visible algae, and macroscopic growths in small ponds and meltwater trickles. Particular attention was given to saturated ground with green surface crusts of algae where wastewater from the base's kitchen ran from a drainage pipe before flowing about five metres down a rocky slope and into the sea.

Direct microscopic examination was made of macroscopically visible algal communities. All samples were inoculated onto agarised BBMS and moist plate enrichment cultures were made of a selection of samples. The latter consisted of sample material moistened with sterile water with sterilised microscope coverglasses gently pressed onto the surface. Following incubation these were removed and their undersurfaces examined for algae.

2.4. Investigation of dispersal of algae by human and natural vectors in Antarctica

During January and December of the 1990–91 Antarctic summer, a "Jet" spore sampler was used to detect airborne algae outside Scott Base as well as at "pristine" sites distant from human habitation. Particles were collected and cultures inoculated and incubated as described in 2.1 above.

The "pristine" sites were chosen to provide background counts of airborne diaspores in comparison with Scott Base where human activity, including dust disturbance by vehicles, is considerably greater. A site in the southern Victoria Land ice-free desert was in Victoria Valley at the western end of Lake Vida (77°23′S 161°26′E). A second site was on the Ross Ice Shelf (78°01′S 169°42′E) at a distance of approximately 40 km from the nearest rock outcrop.

Snow in late-lying drifts close to Scott Base, and from surface deposits on the Ross Ice Shelf, was examined for algal diaspores as an indirect method of detecting algae which might have been blown onto the snow. Surface snow samples were collected and melted using aseptic technique. The meltwater was filtered through 0.45 μm membrane filters and these were then placed on the surface of agarised BBMS medium. Four samples varying in volume from 25–925 m*l* were collected at Scott Base. On the Ross Ice Shelf 15 samples were taken varying in volume from 750–1000 m*l* giving a total of 13.2 litres of filtered meltwater. The cultures were incubated and algae isolated and identified as described in 2.1 above.

To examine the possibility of algae being transported to "pristine" localities on equipment and clothing, samples were taken from the campsite on the Ross Ice Shelf. Sterile swabs were used to wipe the surfaces of equipment and these were then used to inoculate cultures. Also, visibly dirty snow close to the campsite tents was melted, filtered and cultured as described above.

2.5. *Tests on the survivability of potential colonizers and indigenous Antarctic algae*

Unialgal clonal cultures of chlorophytan, xanthophytan and eustigmatophytan algae, from the collection at the University of Canterbury, were used for survivability experiments. The range of algae tested included; i) indigenous Antarctic algae isolated during previous investigations of "pristine" Antarctic habitats, ii) potential Antarctic colonizers isolated in New Zealand (2.1 above), iii) exogenous algae at Scott Base isolated from imported vegetables (2.2 above) and iv) algae from a typical moist New Zealand garden soil.

In the laboratory, cells from actively growing, eight day cultures were exposed to harsh conditions which mimicked those likely to be encountered by Antarctic microorganisms. Treatments and controls used membrane filters upon each of which approximately 250 cells had been deposited by filtration of appropriate numbers of cells suspended in liquid BBM. Three replicate filters of each strain were exposed to each treatment and three were used as controls. Treatments were; five consecutive freeze-thaw cycles (−15°C for 40 min followed by warming to approx. 18°C for 15 min), exposure to high salinity (3 h exposure to 100 g l^{-1} sodium chloride), and desiccation (72 h over silica gel at approx. 18°C). Each filter was placed on the surface of agarised BBM. Following three weeks incubation (see 2.1) colonies were counted on treatment and control cultures. Data were subjected to ANOVA and viability was deemed to have been significantly decreased where a count following treatment was less than the control at $P<0.05$.

3. Results

3.1. Identity of potential Antarctic colonizers

In most cases identification was made only to generic level. A total of over 50 taxa were detected as potential Antarctic colonizers (Table 1). These were predominantly Chlorophyta (30 taxa) followed by Cyanophyta (8 taxa), Bacillariophyta (6 taxa), Xanthophyta (5 taxa) and Eustigmatophyta (1 taxon). A total of 34 taxa were isolated in New Zealand (see 2.1) and 25 from soil adherrent to fresh vegetables on Scott Base (see 2.2). Moss protonema also developed on the latter cultures.

Eleven of the taxa were from genera which have not been recorded as indigenous to the Ross Sea region (indigenous taxa taken from all the literature on Ross Sea region's algae and from personal unpublished observations).

3.2. Establishment of exogenous algae

Direct microscopic examination of macroscopic growths of algae occurring in the vicinity of Scott Base as well as culture studies on both these and desiccated, sandy soils did not reveal the presence of exogenous algae. The 20 taxa detected have also been recorded from "pristine" habitats in the Ross Sea region (Table 1). Fourteen of these were also detected as "potential Antarctic colonizers". However, because all were identified only to generic level it is not yet possible to make confident statements with regard to their similarity at species and intraspecific levels.

3.3. Dispersal of algae by human and natural vectors in Antarctica

Despite sampling large volumes of air, very few airborne diaspores were detected in Antarctica (Table 2). None were found at the "pristine" sites and only 10 at Scott Base. In comparison the concentrations in Christchurch air were two orders of magnitude greater under similar conditions of wind speed.

The six taxa recovered from Antarctic air (Table 1) have been found at "pristine" sites. All except *Chlorellidium* were also found as potential Antarctic colonizers.

Cultures inoculated with particles filtered from snow collected near to Scott Base produced large numbers of algae. Colonies on all culture plates were too abundant to count. Nine taxa were identified (Table 1). All have been found in "pristine" habitats. Additionally, seven were detected as potential Antarctic colonizers.

No algae were found in melted snow from the Ross Ice Shelf.

Similarly, attempts to culture algae which might have been transported to the Ross Ice Shelf site on clothes and equipment also failed to detect any algae.

3.4. Survivability of potential Antarctic colonizers and indigenous Antarctic algae

The responses of individual strains are displayed in Table 3 and a summary of the responses of all strains from each category of strain origin are shown in

Table 1. List of algae found as potential Antarctic colonizers and their occurrence at Scott Base and in "pristine" habitats of the Ross Sea regions.

Taxa	Potentially invasive algae		Scott Base algae	Indigenous Ross Sea regions algae
	New Zealand	Scott Base		
Cyanophyta				
Anabaena		V		I
Calothrix	A			I
**Cylindrospermum*		V		
Nostoc	A	V	MS	I
Oscillatoriaceae		V	M	I
*cf. *Pleurocapsa*	A			
Scytonema	A			I
Tolypothrix		V		I
Xanthophyta				
Botrydiopsis	AB	V	ADMS	I
Chlorellidium			A MS	I
Heterococcus	A	V	DMS	I
Heterothrix	AB	V	A MS	I
Tribonema			M	I
Eustigmatophyta				
**Eustigmatos*		V		
Bacillariophyta				
Achnanthes brevipes			M	I
Hantzschia amphioxys	A	V	M	I
Navicula cf. *atomus*	A	V	MS	I
Navicula muticopsis			DM	I
Navicula spp.		V	A M	I
Pinnularia borealis	A			I
Chlophyta				
*cf. *Apatococcus*		V		
Binuclearia			MS	I
Chlamydomonas	A	V	D	I
Chlorella	ABE		A M	I
**Chlorella* cf. *reniformis*	B			
Chlorella cf. *vulgaris*	A	V		I
Chlorococcum	A E	V		I
Chlorosarcinopsis	A E	V		I

Table 1. (Continued).

Taxa	Potentially invasive algae		Scott Base algae	Indigenous Ross Sea regions algae
	New Zealand	Scott Base		
Coccomyxa	E			I
Cylindrocystis		V		I
cf. *Desmococcus*	A			I
Diplosphaera	A	V		I
Geminella	A E			I
Klebsormidium	A E	V		I
**Lobococcus*	B			
**Monoraphidium*	A			
Muriella	A	V		I
**Myrmecia*	A			
Neochloris	B		D	I
Neospongiococcum	A	V	DMS	I
*cf. *Planophila*		V		
Pseudococcomyxa	A			I
**Pseudotetracystis*	A			
cf. *Radiosphaera*			M	I
Raphidonema			M	I
**Spongiococcum*	A E			
Stichococcus	A	V	A	I
Tetracystis	A E	V	DMS	I
*Trebouxia***	A			I
Ulothrix	ABE			I

* Taxa found only as potential Antarctic colonizers and not in pristine habitats of the Ross Sea regions.

** It is probable that colonies of *Trebouxia* which appeared in these cultures derived from lichen propagules.

Key: Algae observed in the following sample materials: A, airborne propagules; B, dry dust on boots of Antarctic expeditioners boarding Antarctic-bound aircraft; E, dry dust on equipment and stores at N. Z. Antarctic Programme stores, Christchurch, New Zealand; V, soil traces on fresh vegetables imported to Scott Base; D, dry soil outside Scott Base; M, macroscopic, visible algal growths outside Scott Base; S, snowdrifts outside Scott Base; I, indigenous Antarctic algae.

Table 2. Abundance of airborne diaspores of algae in Antarctica and New Zealand.

Location	Volume of air sampled m^3	Diaspores		Wind speed range ms^{-1}
		Total	m^{-3}	
Scott Base	1800	10	0.006	0–8
Ross Ice Shelf	1800	0	0	1.7–7.2
Victoria Valley	4140	0	0	2.2–8.6
Christchurch, N. Z.	281	196	0.700	1.1–5

Table 3. Survivability of Antarctic and New Zealand algae following exposure to freeze-thaw cycles, high salinity and desiccation.

Strain number, identification and origin		Survivability[1]			
		F	S	D	Total
Antarctic indigenous					
582	*Chlorella reisiglii*	5	5	5	15
392	*Stichococcus* sp.	5	5	5	15
429	*Stichococcus* sp.	5	5	5	15
581	*Chlorella saccharophila*	5	5	4	14
631	*Stichococcus* sp.	5	5	4	14
394	*Chlorella vulgaris*	4	5	5	14
600	*Stichococcus* sp.	4	5	5	14
485	*Botrydiopsis* sp.	5	4	3	13
645	*Botrydiopsis* sp.	5	5	nd	10
577	*Chlorella protothecoides*	5	3	3	11
679	*Pseudococcomyxa simplex*	5	1	5	11
406	*Pseudococcomyxa simplex*	3	1	5	9
638	*Botrydiopsis* sp.	2	1	5	8
586	*Pseudococcomyxa simplex*	1	4	1	6
Antarctic introductions - soil on fresh imported vegetables					
C10	*Neospongiococcum* sp.	0	2	5	7
C64	*Chlorella vulgaris*	1	5	nd	6
C18	*Muriella* sp.	1	3	nd	4
C24	*Neospongiococcom* sp.	0	1	2	3
C19A	cf. *Planophila* sp.	1	1	1	3
C8A	*Chlorococcum* sp.	0	1	1	2
C57	*Eustigmatos* sp.	0	1	1	2
C8B	*Chlamydomonas* sp.	0	0	0	0
C15	*Chlorococcum* sp.	0	0	0	0
New Zealand, potential Antarctic colonizers - airborne, and dust on boots and equipment					
CH11	*Chlorella* sp.	5	5	5	15
CH33	*Chlorella* sp.	5	5	5	15
CH32	*Lobococcus* sp.	5	5	5	15
CH35	*Neochloris* sp.	5	5	5	15
CH38	*Stichococcus* sp.	5	5	5	15
CH20	*Chlorella* sp.	3	5	4	12
CH27	*Botrydiopsis* sp.	3	3	5	11
CH26	*Chlorella* sp.	nd	5	5	10
CH30	*Chlorella* sp.	5	2	2	9
CH36	*Chlorella* sp.	4	4	nd	8
CH40	*Botrydiopsis* sp.	1	1	2	4

Table 3. (Continued).

Strain number, identification and origin		Survivability[1]			
		F	S	D	Total
New Zealand - typical moist garden soil					
RS601	*Pseudoccomyxa simplex*	4	5	4	13
RS114	*Scenedesmus* sp.	0	1	5	6
RS2	*Tetracystis* sp.	0	1	3	4
RS10	*Chlorella* sp.	0	1	1	2
RS8	*Chlorococcum* sp.	1	0	1	2
RS16	*Chlorococcum* sp.	0	0	0	0
RS308	*Scenedesmus* sp.	0	0	0	0

[1] Treatments are: F, freeze-thaw; S, high salinity; D, desiccation. Survivability is scored as; 0–4, significant reduction in viability following treatment ($P < 0.05$); 0, no survival; 1, 1–24% survival; 2, 25–49%; 3, 50–74%; 4, > 74%; 5, no significant reduction in viability detected ($P>0.05$). Total=sum of rankings for all three treatments; minimum 0, maximum 15. "nd" indicates that no data is available.

Fig. 1. Two general responses are apparent. The majority of strains of indigenous Antarctic algae and potential Antarctic colonizers isolated from air and dust in New Zealand showed high levels of survival of all treatments. In contrast, the majority of strains from soil adhering to vegetables imported into Antarctica and those from a typical moist New Zealand garden soil showed either no survival or much reduced survival of all treatments. These strains were also generally more susceptible to freeze-thaw cycles than to high salinity or desiccation.

On the whole, individual strains showed similar responses to all three treatments (Table 3). However, some varied markedly in their responses, *e.g.* strain C10, *Neospongiococcum* sp., and RS114, *Scenedesmus* sp., showed no survival of freeze-thaw but were unaffected by desiccation. There were also differences in the responses of different strains of the same genus, *e.g.* strains 485 and 638 of *Botrydiopsis*, and of different strains of the same species, *e.g.* strains 679, 586 and RS601 of *Pseudococcomyxa simplex*.

4. Discussion

The isolation of algae from soil coating fresh vegetables is a first confirmation that alien algae are being dispersed to Antarctica by human activity. The even wider range isolated in New Zealand from material likely to be transported to Antarctica demonstrates the additional potential that exists. Future studies should concentrate more on diaspores actually arriving in Antarctica by sampling people and equipment as they disembark at Antarctic stations.

Ten of the potential colonizers are from genera not known to occur in the

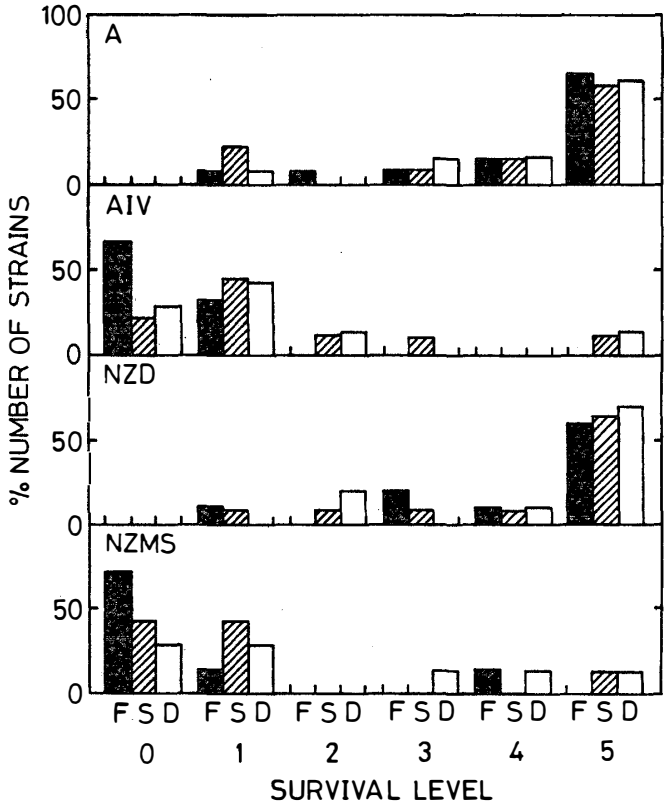

Fig. 1. Survivability of algae subjected to harsh conditions in the laboratory. The diagram indicates the percentage of strains isolated from four different sources which survived at each of six levels following three treatments. Treatments are: F, freeze-thaw cycles; S, high salinity; D, desiccation. Sources of strains are: A, indigenous Antarctic isolates; AIV, exogenous Antarctic algae from soil traces on fresh vegetables; NZD, potential Antarctic colonizers from desiccated material (airborne particles, dust on equipment and crates, dust on boots of Antarctic expeditioners) sampled in New Zealand; NZMS, algae isolated from a moist garden soil in New Zealand. Survival levels are: 0–4, significant reduction in viability following treatment ($P<0.05$); 0, no survival; 1, 1–24% survival; 2, 25–49%; 3, 50–74%; 4, >74%; 5, no significant reduction in viability detected ($P>0.05$).

Ross Sea region. Of these, two from vegetable surfaces, *Cylindrospermum* and *Eustigmatos*, have particularly distinctive morphological and cytological features. These could be useful "model" organisms (VISHNIAC, 1992) in that their spread could be monitored relatively easily if they became established in the outside environment. The terminal heterocysts and akinetes of *Cylindrospermum* and the distinctive polygonal pyrenoids of *Eustigmatos* allow both to be recognised by direct microscopic examination of sample material without the need for cultures. The remaining 8 potential colonizers from the Chlorophyta would be considerably more difficult to distinguish without resort to examination of isolates in culture.

The 32 taxa recorded both as potential colonizers and indigenous to the Ross Sea region require careful comparison in culture in order to establish whether

strains from each origin are significantly different. As well as utilising traditional morphological and life-history information, detailed characterisation could utilise comparison of physiology, biochemistry and also genetic analysis as suggested by WALTON (1990).

This study used only a single medium which would have selected for the growth of only a proportion of the total range of algae in the samples. Future investigations should utilise a range of media, both agarised and liquid, designed to allow growth of as wide a range of terrestrial and aquatic algae as possible.

We found no evidence that any of the potential colonizers had been introduced into the external Antarctic environment, even in algae-rich habitats close to Scott Base. Notably, the enriched algal growths under the waste outflow bringing grey water from the kitchen consisted of indigenous taxa. However, these perturbed habitats are probably the ones where introduced algae are most likely to establish and should be a focus of future searches for exogenous taxa.

Detection of airborne propagules in the vicinity of Scott Base demonstrates that if exogenous algae did become established then airborne dispersal could aid their spread to other localities. However, the efficiency of airborne dispersal of Antarctic algae still requires elucidation. The "Jet" spore sampler utilised in this study might not be the best apparatus for their detection especially if most dispersal occurs by saltation, within a few centimetres of the ground surface (BENNINGHOF and BENNINGHOF, 1985) and below the sampler's air intake (HAWES, 1991). Failure to detect significant numbers might also have been related to the relatively low wind speeds during sampling (Table 2). The maximum of 8.6 m s^{-1} is well below the 40 ms^{-1} which would be exceded regularly at all sampling locations and which would more readily dislodge particles from the ground surface.

The survivability experiments demonstrated that some potential colonizers are as equally resistant to harsh conditions as are indigenous Antarctic strains. Desiccation during dispersal appears to select for taxa with high survivability, as most of those from moist soil on imported vegetables showed low survivability similar to those from a moist New Zealand soil.

It is possible that algae with low survivability of the harsh experimental treatments could still be dispersed to, and survive in, relatively benign Antarctic habitats. In the Ross Sea region such habitats would include warm geothermal soils and permanently ice-covered lakes where liquid water occurs all year. High altitude geothermal soils support the growth of several taxa unknown in all other habitats (BROADY, 1993). This suggests that natural airborne dispersal has brought propagules which cannot establish outside this relatively mild microenvironment. Precautions such as surface-sterilising boots and equipment used in geothermal soils are essential to minimise risks of exogenous introductions by human activity.

Deliberate introduction of exogenous algae into the Antarctic environment in order to test for their survival and growth would be unwise, unethical and would contravene the Antarctic Treaty (Agreed Measures for the Conservation of Antarctic Fauna and Flora, Article IX). The alternative is to expose them to laboratory conditions which closely model the conditions which they would

encounter in Antarctica. The survival experiments performed here are only a limited example of what is required. They could be extended by using natural Antarctic soils and waters to test for survival and growth under realistic physico-chemical conditions, including regimes which model seasonal changes. The ability of exogenous algae to colonize in the presence of communities of indigenous algae could also be examined.

In order to assess the continent-wide significance of the human vector for introduction of exogenous algae, studies need to be extended to other stations. The diversity of potential colonizers will differ depending on the region of origin of people and materials arriving in Antarctica. Of particular importance are studies in maritime Antarctica where the relatively mild conditions might be more conducive to the establishment of exogenous taxa.

Two more areas of ignorance need to be addressed before we can reach conclusions about the significance of human introductions. First, the diversity and abundance of diaspores transported by natural vectors requires study. The design of samplers and sampling regimes are currently under development (LACEY and MCCARTNEY, 1992; WYNN-WILLIAMS, 1992). Secondly, we need to complete the inventory of Antarctic indigenous algae and compile detailed descriptions of all species (BROADY, 1992; VISHNIAC, 1992). This is essential base-line knowledge for the recognition of algae of exogenous origin.

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