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Antarctic moss coping with the ozone hole.

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Introduction

In this study we surveyed the natural variability in surface reflectance in moss species from continental Antarctica. In Wilkes Land, Antarctic, conditions are cold and usually very arid, resulting in lichens dominating the rocky, ice-free areas. The moss community is well developed for the region, but is restricted to locations where free water is available for at least some of the summer (November-March). Compared to lower latitudes, levels of UV radiation have historically been low in Antarctica, but for the past few decades Antarctica has experienced large increases in incident UV-B radiation due to reductions in concentrations of stratospheric ozone (Frederick and Snell, 1988). The heat balance of moss, its photosynthetic characteristics and the impact of enhanced UV radiation are likely to be partially dependent on surface reflectance characteristics and pigment composition.

The first aim of this study was to assess the surface reflectance and pigment composition of the three dominant moss species. In measuring surface reflectance we also wanted to evaluate the potential of using hyperspectral imagery to remotely sense plant communities. In many areas of Antarctica, plant communities are inaccessible making it difficult to map distribution and assess biodiversity. In addition, conventional mapping techniques are time consuming and can be destructive. Recent developments in remote sensing and improvements in resolution make these techniques attractive for both baseline measurements and for monitoring change in communities due to either climate change or human impacts. These methods would be particularly useful if plants can be differentiated at the species level. The second aim of our study was to understand how spectral response of moss related to photosynthetic processes. Surface reflectance properties of leaves are used as indicators of photosynthetic function in remote sensing of vegetation (reviewed in Field *et al.* 1994). Changes in surface reflectance of intact leaves have been directly correlated with changes in photosynthetic processes in many higher plant taxa despite the difficulties posed by differences in the scale of physiological and remotely sensed measurements (Gamon *et al.* 1995 and 1997; Field *et al.* 1994).

Materials and methods

The three most common moss species, *Grimmia antartici, Bryum psuedotriquetrum* and *Ceratodon purpureus* were sampled from sites close to the Australian base at Casey, Continental Antarctica (66˚17'S, 110˚32"E), as 2 cm^2 sections cut from turves. A diffuse reflectance accessory fitted to a scanning spectrophotometer (GBC UV-Vis 918, GBC Australia), was used to measure surface reflectance of moss between 200 – 900 nm. The photosynthetic reflectance index (PRI) was calculated as described by Gamon *et al.* 1997. The amplitude of the reflectance change at the red-edge ($\delta R/\delta\lambda_{RE}$) and the position of the red-edge (λ_{RE}) as defined by Horler *et al.* (1983) were calculated from the first derivative spectra.

Chlorophylls and carotenoids were extracted in acetone and quantified by high pressure liquid chromatography using a method adapted from Gilmore and Yamamoto (1991). Anthocyanins were determined using the differential pH method of Francis (1982). UV-B absorbing pigments were extracted in MeOH:HCl:water (79:20:1) and determined spectrophotometrically. The chlorophyll fluorescence parameter Fv/Fm was measured with a PAM 2000 (H. Walz, Germany) as described in Robinson *et al.* 2000. Tests of the influence of species on pigments and reflectance were performed using ANOVA.

Results

Reflectance spectra

Reflectance spectra of mosses were generally similar in shape to those observed for angiosperm leaves (Fig. 1A) with the major features of the spectra being those indicative of chlorophyll. Examination of the 1st derivative of the spectra (Fig. 1B) showed typical peaks at the green and red edges (approximately 550 nm and 700 nm respectively). However differences between the species are apparent. The shape of the reflectance spectra of *B. pseudotriquetrum* was typical of that observed in healthy, green leaves of higher plants, but for the other two species the reflectance in both the near infrared (NIR) and the green were much less pronounced. The R_{850} and R_{550} were significantly higher in *B. pseudotriquetrum* than for the other species and the red edge occurred at a longer wavelength (Table 1). Reflectance in the UV was low compared to the visible and NIR for all species.

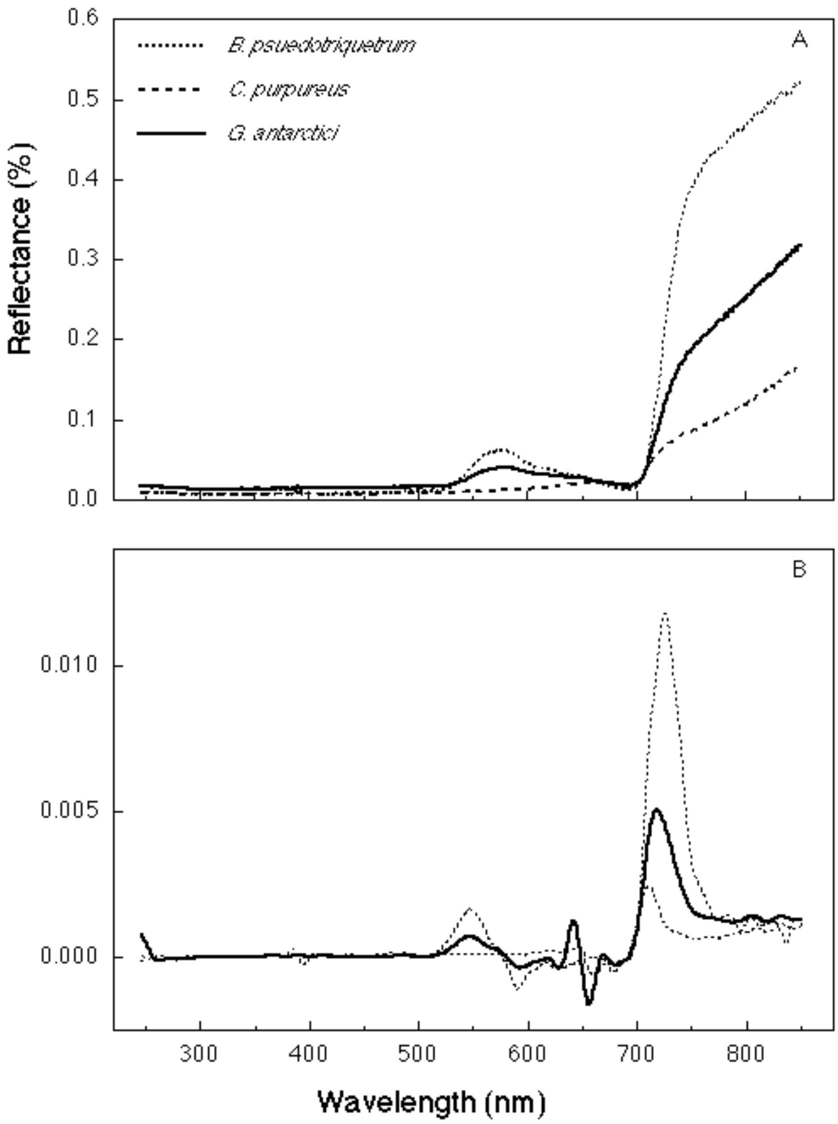

Fig. 1. Representative reflectance spectra (A) and first derivative (B) of *G. antarctici B. pseudotriquetrum* and *C. purpureus*.

Table 1. Surface reflectance characteristics for three common moss species in Continental Antarctica, N = 11, 12, 61 respectively.

	B. pseudotriquetrum	*C. purpureus*	*G. antarctici*	**F**	**P**
Reflectance					
R_{850}	0.388 ± 0.026	0.274 ± 0.025	0.321 ± 0.011	5.092	0.0083
R_{550}	0.056 ± 0.0059	0.033 ± 0.0057	0.035 ± 0.0025	5.094	0.0083
R_{280}	0.009 ± 0.001	0.0078 ± 0.001	0.0071 ± 0.0004	NS	
$\delta R/\delta\lambda_{RE}$	0.0101 ± 0.0001	0.0060 ± 0.0001	0.0068 ± 0.0001	8.74	0.0004
λ_{RE}	705.4 ± 1.9	700.6 ± 1.0	700.4 ± 0.5	7.33	0.0012
PRI	-0.1601 ± 0.0277	-0.1598 ± 0.0153	-0.1720 ± 0.0087	NS	

Pigment characteristics

Pigment concentrations varied between species (Fig 2). *B. pseudotriquetrum* and *G. antarctici* had higher chlorophyll compared to *C. purpureus*. *G. antarctici* and *C. purpureus* had more total carotenoid on a chlorophyll basis than *B. pseudotriquetrum* and significantly higher levels of the xanthophyll cycle pigments particularly in the photoprotective forms. Since samples were frozen several hours after collection the levels of A and Z represent sustained retention of the photoprotective forms of these xanthophylls. *C. purpureus* had higher levels of anthocyanins (on a chlorophyll basis) than *G. antarctici* or *B. pseudotriquetrum,* whilst *B. pseudotriquetrum* had the highest levels of UV-B absorbing pigments.

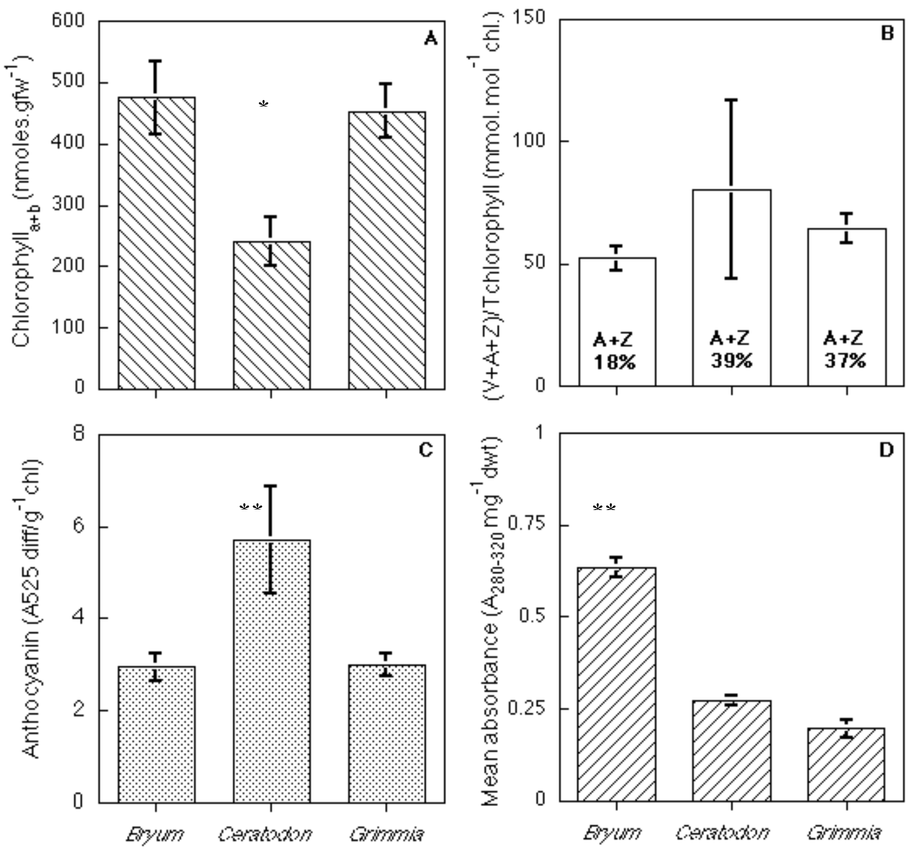

Fig. 2. Concentration of total chlorophyll (A) xanthophyll cycle pigments (B) anthocyanins (C) and UV-B absorbing pigments (D) in *B. pseudotriquetrum, C. purpureus* and *G. antarctici*. Data represent means and SEM, n as in Table 1. The percentage of the xanthophylls sustained as A and Z is shown as a percentage in B. Double and single asterisks indicate significant species effects at the $P < 0.05$ and 0.10 levels respectively.

Relationships between reflectance, plant pigments and photosynthetic function

Overall, correlation between surface reflectance indices and plant pigment contents was low. Total chlorophyll concentration within moss was loosely positively correlated with the $\delta R/\delta\lambda$ (*Rho* = 0.511), and its position, λ_{RE} (*Rho* = 0.363). The photochemical reflectance index (PRI), a tool developed to remotely assess plant stress (Gamon *et al.* 1997) was negatively correlated with both the total pool size of the XCP and also the proportion as Z and A (*Rho* = -0.402, and -0.535 respectively). The PRI was positively correlated with the chlorophyll fluorescence parameter, F_v/F_m measured in darkness (*Rho* = 0.626).

Discussion

The surface reflectance parameters most sensitive to differences between moss species were those in the visible region (R_{550}), and the features of the red-edge (λ_{RE} and $\delta R/\delta\lambda$) with *B. pseudotriquetrum*, having higher green and NIR reflectance than the other species. This was not associated simply with differences in chlorophyll concentrations, which were higher than those of *C. purpureus* but similar to that measured in *G. antarctici* . *B. pseudotriquetrum* is morphologically distinct from the other two species, having much larger gametophytes with larger "leaves" and the plants are densely packed into the turf. The other two species are similar in size, but in *C. purpureus* plants are also densely packed whereas *G. antarctici* plants are more loosely distributed within the turves. These factors could influence the chlorophyll content on an area basis and hence the reflectance parameters. However, differences observed in reflectance characteristics among species, especially those in the NIR region, maybe more strongly influenced by differences in plant morphology than by physiological factors.

The sensitivity of the surface reflectance indices to species suggests that mapping of moss communities might be possible using hyperspectral sensors. It seems likely that a high spectral and spatial resolution sensor such as *casi* (Compact Airborne Spectrographic Imager), programmed to detect narrow wavebands in the visible and NIR, could differentiate between species. These methods have already proven useful in the mapping of littoral communities (Bajjouk *et al.* 1996). Remote sensing could provide an effective and nondestructive method of mapping current communities and monitoring impacts of climate change. Despite sensitivity of surface reflectance characteristics to species, surface reflectance indices were not strongly correlated with pigment concentrations, with the exception of the correlation between PRI and XCP. PRI also correlated with the chlorophyll fluorescence parameter F_v/F_m, a measure of PS II function, as has been shown by Gamon *et al*. (1997). Pigments which could protect moss from excess PAR and particularly UV radiation, were generally higher in the cosmopolitan species *C. purpureus* and *B. pseudotriquetrum* than the endemic species *G. antarctici*. The apparent lack of photoprotective potential suggests this species may suffer under predicted global change scenarios.

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