

ECOLOGY OF TERRESTRIAL ALGAE OF THE FELLFIELD ECOSYSTEMS OF SIGNY ISLAND, SOUTH ORKNEY ISLANDS

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ABSTRACT. The temporal and spatial distribution of microalgae in an immature Antarctic fellfield ecosystem is described. These are related to the growth requirements of the algae and their ability to withstand freezing and desiccation. *Phormidium* is the most successful alga in these ecosystems and plays an important role in the soil-binding process.

INTRODUCTION

Jane Col on Signy Island, South Orkney Islands, was selected as one of the main study sites for the British Antarctic Survey Fellfield Ecology Research Programme (FERP) as an example of an extremely immature fellfield ecosystem (British Antarctic Survey, 1982). It is about 150 m above sea level and has only recently been exposed by the retreating ice-cap, and therefore provides an ideal site for the investigation of early colonization stages. It has been demonstrated that bacteria, cyanobacteria and algae are the primary colonizers of the fellfield soils (Smith and Coupar, 1986; Wynn-Williams, 1988*a*), and that these play an important role in the binding of soil particles.

The algae living in such habitats are exposed to extremes of environmental stress, being unprotected by the buffering that may occur in more advanced communities caused by their increased retention of water (Walton, 1982). The major forms of stress are freeze-thaw cycles (Chambers, 1966; Walton, 1982) and desiccation (Northover and Grimshaw, 1967). The algae can therefore be used to test the second hypothesis of the FERP, namely that survival and occupation of such habitats is limited by water availability rather than by the effects of temperature *per se* (British Antarctic Survey, 1981).

Previous studies on the algae of Signy Island have concentrated on taxonomic aspects (Broady, 1979*a*) and population dynamics (Broady 1977, 1979*b*). The present investigation employed a more ecophysiological approach to study the colonization and survival of the algae in the fellfield ecosystems. The work was undertaken at Signy Island between December 1986 and March 1988, and some of the preliminary results are reported here.

METHODS

Three sub-sites were established in a network of patterned ground on Jane Col for the study of temporal changes in the algal communities. Two of these were areas of seemingly bare fines, while the third was visibly colonized by an algal felt. Samples were collected at regular intervals, weekly in summer (January to March), less frequently during the rest of the year, using modified 5-ml syringe corers (12 mm diameter). From each site four cores were used for chlorophyll *a* analysis, as an estimate of algal biomass, following extraction into hot 90% methanol (Marker and others, 1980). Three to six cores were used for direct microscopic examination of the

algae following overnight attachment to coverslips (Broady, 1979a). Photomicrographs of the flora were returned to UK for image analysis (Wynn-Williams, 1988b), to determine the area of soil coverage of the important taxa and morphotypes. Small samples of the algal felt were oven dried (120°C), stored frozen (-20°C) and analysed for phosphorus (Eisenreich and others, 1975) or carbon and nitrogen (Hilton and others, 1986) content.

Microclimate data were recorded throughout the study using a Grant Squirrel data logger (Smith 1988a). Thermistor sensors were distributed horizontally and vertically about a soil polygon. In 1988 relative humidity probes and additional thermistor sensors were added to the study polygons. Also in 1988, the soil water content of the polygons was determined on each sampling date.

In February 1988 an additional two polygons were studied in detail. Using the methods described above the horizontal and vertical distribution of chlorophyll *a* and algae in the polygons were determined. Field samples were also cultured in the laboratory for two weeks at a temperature of 10°C, a photon flux density of 50 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and supplemented with either distilled water or culture medium (Davey, 1988). The investigation into the horizontal distribution of the algae was extended by the collection of spot-samples from (i) many polygons on Jane Col, (ii) areas of soil from other fellfield sites on Signy Island, and (iii) comparable fellfield sites on South Georgia.

The dominant species of algae from the field samples were established in culture. Three of these, *Phormidium*, *Rhizoclonium* and an as yet unidentified coccoid chlorophyte were used in experiments to determine the growth rates of the algae under different irradiance (1–167 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and temperature (0–20°C) regimes using a thermogradient bar (Smith and Coupar, 1986). Experiments were also carried out to determine the resistance of the algae to desiccation using the vital stain Auramine O (Sigma Chemical Co. Ltd).

Two mat-forming algae occur on Signy Island, *Prasiola* and *Phormidium* (Broady, 1979b). These were used to study the responses of the algae to drying and freezing. Two techniques were used: algal photosynthesis was measured by the method of Harrison and others (1986) using an infra-red gas analyser (Analytical Development Co.), at photon flux densities of either 40 or 300 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and temperatures of 5 or 10°C, while cell viability was determined using Auramine O. Samples were air dried to near dry weight or frozen to -15°C with or without excess water.

RESULTS AND DISCUSSION

Algal periodicity

Changes in the algal biomass, as measured by chlorophyll *a* concentration, for a typical polygon are shown in Fig. 1. Biomass maxima occurred in mid-summer, after which a decline proceeded to a winter minimum. In 1987/88 an earlier maximum was also observed, coinciding with the spring melt period, but before the site was clear of snow. Analysis of the species composition of the community is not yet complete. However, it is clear that spring growth consisted mainly of filamentous green algae, notably *Rhizoclonium* and *Ulothrix*, which declined once the site was free of snow. Summer growth was dominated by *Phormidium* species with diatoms, especially *Pinnularia*, as sub- or co-dominants.

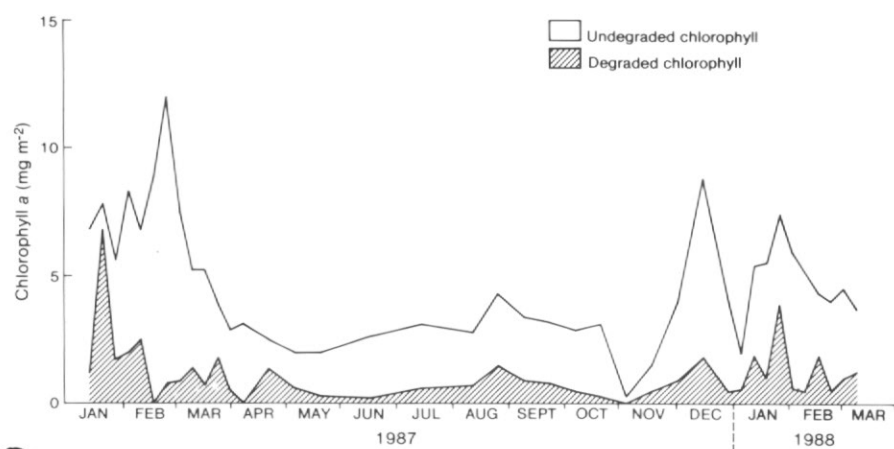


Fig. 1. Seasonal changes in the chlorophyll *a* content of the fines of a soil polygon on Jane Col.

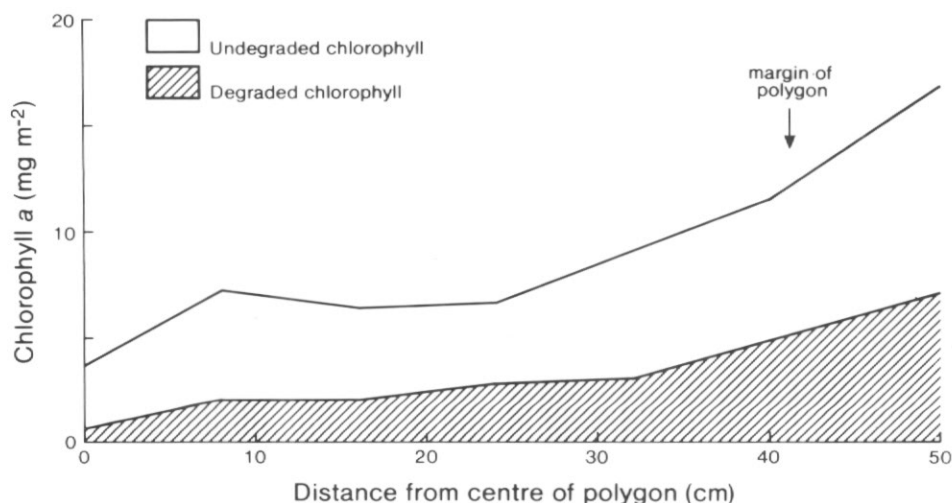


Fig. 2. Horizontal distribution of chlorophyll *a* across a soil polygon on Jane Col.

Spatial distribution of the algae

The algae living on the soil fines appear to be restricted to a very thin crust on the surface, with little material occurring below this. The horizontal distribution of chlorophyll across a polygon is shown in Fig. 2. There was a marked increase in biomass towards the more stable margin of the polygon. In the example illustrated there was no macro-vegetation around the polygon, although a similar distribution of chlorophyll was observed from a polygon where mosses grew around the stable margin. There was some evidence that the algae were more likely to form close aggregations in the denser communities, and that there was an increase in species diversity; these observations may be related, the colonies of *Phormidium* providing favourable sites for the growth of less environmentally tolerant species.

Little obvious change in the species composition of the algal communities was

observed following incubation in either water or culture medium. However, analysis of the change in the numbers of algae is not yet complete.

Observations on a number of polygons on Jane Col indicated that *Phormidium* spp. were the dominant components of all the communities. However, there were major differences in the algal floras between polygons, with many different taxa co- or sub-dominant with the *Phormidium*. It is suggested that each polygon is acting as a separate ecosystem, and that in these slow-growing communities the first taxa to become established, through random inoculum input, can remain dominant for a long period of time.

Culture studies

No growth was observed in any species at 0°C over the 30-day course of the experiments. This may have been caused, in part, to some ice formation in the culture vessels at this temperature, although complete freezing did not occur and most taxa survived freezing at these temperatures.

Under all other conditions the coccoid chlorophyte was the fastest growing species tested, reaching 3.0 divisions day⁻¹. Growth of this species increased with increasing irradiance or temperature, although there was some inhibition at high irradiance/low temperature or low irradiance/high temperature conditions. However, it was highly susceptible to the effect of desiccation, and this factor probably accounts for its failure to dominate the fellfield ecosystem where it occurs only amongst aggregates of other algae, notably *Phormidium autumnale*.

Growth of *Phormidium* showed a similar pattern to that of the coccoid chlorophyte, although at lower absolute growth rates. A maximum growth rate of 0.5 divisions day⁻¹ was observed within the range of conditions tested. No growth was observed at the lowest irradiance and very little at temperatures below 5°C.

In contrast to the other two taxa *Rhizoclonium* appears to show greater adaptation to a snow-covered habitat. It grows well under low irradiance and temperature conditions, and is inhibited at high light and temperature to a much greater extent than the other taxa. This may explain its growth in the community in early spring whilst the sites are still covered by snow, and before *Phormidium* commences growth. It is also somewhat susceptible to drying and this, combined with photo- or thermo-inhibition, may explain its replacement by other taxa during the summer, it being too large to be protected by the *Phormidium* mats in the manner of the coccoid alga.

Survival studies

The two taxa of alga studied showed marked differences in their responses to environmental stress. These reflected the different habitats of the algae.

Prasiola was a rapidly growing alga. It recovered well from freezing, but was susceptible to drying (Table I). The detrimental effects of stress were particularly evident at the higher irradiance tested. The use of the vital strain, Auramine O, demonstrated very high inter- and intra-thallus variability in the incidence of cell viability, even in unstressed material. This may account for the high variability in these and other physiological measurements on this alga. The results are consistent with observations that *Prasiola* is opportunistic, being particularly associated with areas of disturbance and nitrogen enrichment caused by seals or penguins (Smith, 1988b).

In contrast, the photosynthetic rates of *Phormidium* were an order of magnitude less than those for *Prasiola*. For example, at 300 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and 10°C, net

Table I. Mean percentage recovery, as measured by net photosynthesis at 10°C before and after the application of stress, of two species of algae following the application of environmental stress. Dessication was to near dry weight, and freezing to -15°C overnight either with or without excess water. $n = 10$ in all cases

Form of stress	Photon flux density ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	<i>Prasiola</i>	<i>Phormidium</i>
Dessication	300	6	77
	40	14	—
Wet-freeze	300	49	89
	40	100	—
Dry-freeze	300	65	0
	40	75	—

photosynthetic rates of *Prasiola* and *Phormidium* were 2.7 and 0.19 mg C (g ash-free weight)⁻¹, respectively. Therefore, in the case of *Phormidium*, it was only possible to make measurements at the higher light intensity. Such an observation supports that from the culture studies in which *Phormidium* was found to be slow-growing at low irradiances. *Phormidium* was susceptible to freezing, but to a reduced extent in the presence of excess water, which probably slowed the freezing process. It was highly resistant to desiccation, showing almost 100% recovery of photosynthesis following drying to constant (near dry) weight (Table I). *Phormidium* has been described as an important coloniser of Antarctic fellfield soils (Wynn-Williams, 1988a), a situation where desiccation resistance may be important. It also contains large amounts of soil particles within the mat, consisting of 60% of its dry weight as ash compared to only 10% in *Prasiola*, reflecting its important role in the soil binding process.

In general, *Phormidium* appears to be the most important and successful of the fellfield algae. It is widespread, demonstrates some resistance to freezing and desiccation and binds large amounts of soil particles into the thallus matrix. However, it is rather slow growing under many of the conditions to which it is exposed, and may be regarded as analogous to K-strategists (MacArthur and Wilson, 1967).

The results presented suggest that water availability is of great importance to the survival of the fellfield algae during the summer. However, it has been shown that light and temperature are significant environmental factors at other times, and that the role of nutrient availability cannot be discounted. Therefore, the second hypothesis of the FERP is not entirely supported by these results.

This investigation has concentrated on the effects of the environment on the survival and growth of algae in the Antarctic fellfields. Further work is required to demonstrate the role that these algae play in the stabilising the substratum and enriching the soil with organic leachates which are crucial to the further development of the ecosystem (Tearle, 1987).

REFERENCES

- BRITISH ANTARCTIC SURVEY. 1981. Terrestrial Biology. (In *British Antarctic Survey Annual Report, 1980-81*. Cambridge, British Antarctic Survey, 48-59.)
- BRITISH ANTARCTIC SURVEY. 1982. Terrestrial Biology. (In *British Antarctic Survey Annual Report, 1981-82*. Cambridge, British Antarctic Survey, 60-2.)
- BROADY, P. A. 1977. The Signy Island terrestrial reference sites. VII. The ecology of the algae of site 1, a moss turf. *British Antarctic Survey Bulletin*, No. 45, 47-62.
- BROADY, P. A. 1979a. The terrestrial algae of Signy Island, South Orkney Islands. *British Antarctic Survey Scientific Reports*, No. 98, 117 pp.

- BROADY, P. A. 1979*b*. The Signy Island terrestrial reference sites. IX. The ecology of the algae of site 2, a moss carpet. *British Antarctic Survey Bulletin*, No. 47, 13–29.
- CHAMBERS, M. J. G. 1966. Investigations of patterned ground at Signy Island, South Orkney Islands. II. Temperature regimes in the active layer. *British Antarctic Survey Bulletin*, No. 10, 71–83.
- DAVEY, M. C. 1988. The effects of nutrient depletion on the sinking velocity and cellular composition of a freshwater diatom. *Archiv für Hydrobiologie*, **112**, 321–34.
- EISENREICH, S. J., BANNERMAN, R. T. and ARMSTRONG, D. E. 1975. A simplified phosphorus analysis technique. *Environmental Letters*, **9**, 45–53.
- HARRISSON, P. M., WALTON, D. W. H. and ROTHERY, P. 1986. The effects of temperature and moisture on dark respiration in the foliose lichen *Umbilicaria antarctica*. *New Phytologist*, **103**, 443–55.
- HILTON, J., LISHMAN, J. P., MACKNESS, S. and HEANEY, S. I. 1986. An automated method for the analysis of 'particulate' carbon and nitrogen in natural waters. *Hydrobiologia*, **141**, 269–71.
- MACARTHUR, R. H. and WILSON, E. O. 1967. *The theory of island biogeography*. Princeton, Princeton University Press.
- MARKER, A. F. H., CROWTHER, C. A. and GUNN, R. J. M. 1980. Methanol and acetone as solvents for estimating chlorophyll *a* and phaeopigments by spectrophotometry. *Ergebnisse der Limnologie*, **14**, 88–90.
- NORTHOVER, M. J. and Grimshaw, H. M. 1967. Seasonal trends in nutrient content of the soil of Signy Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 14, 83–88.
- SMITH, R. I. L. 1988*a*. Recording bryophyte microclimate in remote and severe environments. (In G. J. M., ed. *Methods in Bryology. Proceedings of the Bryological Methods Workshop*, Mainz. Nichinan, Hattori Botanical Laboratory.)
- SMITH, R. I. L. 1988*b*. Destruction of Antarctic terrestrial ecosystems by a rapidly increasing fur seal population. *Biological Conservation*, **45**, 55–72.
- SMITH, R. I. L. and COUPAR, A. M. 1986. The colonization potential of bryophyte propagules in Antarctic fellfield soils. (In *Deuxième Colloque sur les Écosystèmes Terrestres Subantarctiques Comité National français des Recherches Antarctiques*, **58**, 189–204.)
- TEARLE, P. V. 1987. Cryptogamic carbohydrate release and microbial response during spring freeze-thaw cycles in Antarctic fellfield fines. *Soil Biology and Biochemistry*, **19**, 381–90.
- WALTON, D. W. H. 1982. The Signy Island terrestrial reference sites. XV. Microclimate monitoring, 1972–4. *British Antarctic Survey Bulletin*, No. 55, 111–26.
- WYNN-WILLIAMS, D. D. 1988*a*. Microbial colonization of Antarctic fellfield soils. In *Proceedings 4th International Symposium on Microbial Ecology, Ljubljana, Yugoslavia* (in press).
- WYNN-WILLIAMS, D. D. 1988*b*. Television image analysis of microbial communities in Antarctic fellfields. *Polarforschung* (in press).