Response of Pioneer Soil Microalgal Colonists to Environmental Change in Antarctica

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Abstract. There is increasing evidence of climate change in Antarctica, especially elevated temperature and ultraviolet B (UVB) flux within the ozone "hole." Its origins are debatable, but the effects on ice recession, water availability, and summer growth conditions are demonstrable. Light-dependent, temperature-sensitive, fast-growing organisms respond to these physical and biogeographical changes. Microalgae (cyanobacteria and eukaryotic algae), which are pioneer colonists of Antarctic mineral fellfield soils, are therefore highly suitable biological indicators of such changes. In frost-heaved soil polygons containing naturally sorted fine mineral particles, microalgal growth is restricted to a shallow zone of light penetration. By virtue of this light requirement, microalgae are exposed to extreme seasonal fluctuations in temperature (air and black-body radiation), photosynthetically active radiation, UV radiation, and desiccation. Dominance of conspicuous autofluorescent indicator species with distinctive morphology allowed quantification of responses using epifluorescence microscopy, and image analysis of undisturbed, unstained communities. However, the physical changes in climate, although significant in the long term, are gradual. The changes were therefore amplified experimentally by enclosing the communities at a fellfield site on Signy Island, maritime Antarctica, in cloches (small greenhouses). These were made of polystyrene of either UV-transparent or UV-opaque acrylic plastic, with or without walls. During a 6-year period, statistically significant changes were observed in microalgal colonization of the soil surface and in the morphology of filamentous populations. Evidence of community succession correlated with measured changes in local environment was found. Results from Signy Island and at continental sites on Alexander Island suggested that rates of microalgal colonization and community development might change significantly during current climate changes in Antarctica.

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Introduction

Local environmental warming and increased ultraviolet B (UVB) radiation during ozone depletion may have profound effects on the cyanobacteria and eukaryotic algae that are primary colonizers of Antarctic fellfield soils. Despite deviations between global warming models, one scenario for polar regions predicted an annual mean increase of 1.8°C above ambient temperature by the year 2050 [20]. The increase would be 0.9–1.3°C in summer and 3.6–4.3°C in winter. In maritime Antarctica at Signy Island, Davey et al. [11] quantified seasonal variations in ground temperature during the summer of 1987 and their potential influence on soil surface biota. They showed that minimum ground surface temperatures in summer were always close to 0°C, although very few freeze–thaw events extending below −0.5°C occurred during this period. Nevertheless, small elevations in climate temperature may have profound effects on the activity threshold of the surface biota.

Trends in annual ozone depletion predict an annual increase in DNA-weighted UV dose of 40% per decade at 85°S [16]. Polar amplification of these trends makes the fellfield ecosystems of maritime Antarctica at Signy Island (largely outside the “hole”) and coastal continental Antarctica at Alexander Island (inside the ozone hole) especially suitable for comparative monitoring the biological effects of environmental change [26, 28].

Long-term research at the Jane Col fellfield site on Signy Island [22] has focused on the ability of microalgae to initiate the colonization process on recently deglaciated ground. This light-dependent process is vulnerable to environmental change because of the restriction of their growth to the shallow photic zone of the soil profile. It was hypothesized that in the moist habitat of this maritime Antarctic site without major escalation of UV-B radiation, the primary influential factor for microalgal colonization would be ground surface temperature.

Although microalgae respond rapidly to environmental changes, the rate of climate change is relatively slow despite its long-term significance. Changes in temperature must therefore be amplified experimentally using experimental cloches made of polystyrene or acrylic plastic established in the field for long-term studies [25]. This nonirrigated approach is applicable to soils containing sufficient water available for metabolic activity. In arid continental areas, this situation only prevails in oases [15], defined as “areas of restricted size where surface water supports a significant biota in an otherwise barren desert region of ice-free land.” [15]

To demonstrate biological response to change, a standardized representative natural substratum is needed so that replicate samples (including controls) can be taken over extended periods of time. There must also be a capacity for repeated coring without seriously affecting the habitat. Samples must contain responsive organisms that can be quantified reproducibly without disruption of their natural community structure. Mineral fines in the center of frost-sorted polygons of fellfield habitats meet these requirements at Signy Island for a variety of reasons. The fine quartz micaschist material is sorted naturally to provide a relatively flat, homogeneous surface suitable for direct epifluorescence microscopy of autofluorescent cyanobacteria and eukaryotic algae, which, as phototrophs, initiate the colonization process [10]. Their dependence on photosynthetically active radiation (PAR) restricts them to a shallow focal plane, which further assists examination [8, 24]. Quantification by image analysis (IA) is simplified by conspicuous dominant