Antarctic Science 26(4), 341–344 (2014) © Antarctic Science Ltd 2013 doi:10.1017/S0954102013000606

A fern cultured from Antarctic glacier detritus

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Abstract: A fem, *Elaphoglossum hybridum* (Bory) Brack., has been cultured from mineral sediment in cryoconite holes in the ice cap of Signy Island, South Orkney Islands. Its provenance, mode of transport to its Maritime Antarctic destination and the significance of viable exotic propagules as potential colonists are discussed.

Received 31 December 2012, accepted 11 July 2013, first published online 26 November 2013

Key words: bryophytes, cryoconite, *Elaphoglossum hybridum*, long-distance dispersal, propagule banks, pteridophyte, South Orkney Islands

Introduction

The diversity and provenance of the Antarctic flora is now relatively well known, although little is understood about when the main phases of immigration occurred (Bednarek-Ochyra *et al*. 2000, Øvstedal & Lewis Smith 2001, Lewis Smith 2003, Peat *et al*. 2007, Ochyra *et al*. 2008). The contemporary vascular plant flora comprises only two native species, Antarctic hairgrass (*Deschampsia antarctica* Desv.) and Antarctic pearlwort (*Colobanthus quitensis* (Kunth) Bartl.), both restricted to the Maritime Antarctic (Lewis Smith 1984). So far, there is no evidence of any other species having been present at any time during the Holocene, and of the very few non-indigenous species which have become established in recent decades none appears to have succeeded without the aid of human intervention, either intentionally or accidentally (e.g. Lewis Smith & Richardson 2011, Hughes & Convey 2012, Chown *et al*. 2012). The very limited palynological analyses of organic deposits in the Maritime Antarctic have revealed pollen and spores of angiosperms (including *Deschampsia*, *Colobanthus* and several Fuegian species), and unidentified pteridophytes and mosses, over a *c*. 5000 year timescale (e.g. Churchill 1973 p. 80–81, Birkenmajer *et al*. 1985, Kappen & Straka 1988, Björck *et al*. 1991, Smith 1991). Studies of soil propagule banks at several Antarctic sites (Smith 1993, Ayukawa *et al*. 2001, Lewis Smith & Ochyra 2006) have revealed a wide range of bryophyte species which developed from buried propagules when the soils were incubated under a range of temperature and nutrient conditions. Virtually all the species were typical of the local floras and presumed to have originated from these. This was verified by propagule trapping experiments (Smith 1991 and unpublished data, Chalmers *et al*. 1996, Marshall 1996, Marshall & Convey 1997).

During the course of a long-term study of soil propagule banks at several Antarctic sites, mineral detritus from cryoconite holes was cultured. The largely mineral detritus produces a sediment at the bottom of these holes which contains a diversity of diatoms, algae, protozoans, rotifers and tardigrades, as well as vegetative fragments of bryophytes and lichens. Amongst the viable propagules deposited in this unique aquatic habitat was a fern, the identity of which is reported here.

Method

Signy Island (8 x 5 km) lies *c*. 900 km ESE of Tierra del Fuego (see Smith 1990). In November 1999, fine mineral soil from ten cryoconite holes in the surface of the island's ice cap (*c*. 300 m altitude) was collected within an area of *c*. 1 ha (cf. Bonde 1969). Each sample was divided into three sub-samples, of *c*. 100 g fresh weight, which were cultured at room temperature (*c*. 18°C) in the laboratory at Signy research station. The dishes had a perforated base over which was glued an ultra-fine nylon mesh to allow water to penetrate upwards during subsequent cultivation. Initially, no water was added as the fresh soil remained moist. For the first six months the culture dishes were kept sealed to prevent contamination, but examined monthly through the clear polystyrene lid. Later, a small amount of deionised water was added to the tray at regular intervals. The experiment was continued for a further 12 years, with occasional transplantings.

Results

After approximately four weeks, several species of moss and two liverworts began to develop small colonies of shoots from spores or gametophyte fragments deposited in the cryoconite sediment. All were typical of the local flora (the acrocarpous mosses *Bartramia patens* Brid., *Bryum pseudotriquetrum* (Hedw.) Gaertn., Meyer et Scherb., *Ceratodon purpureus* (Hedw.) Brid., *Pohlia nutans* (Hedw.) Lindb., *Syntrichia magellanica* (Mont.) R.H. Zander, and

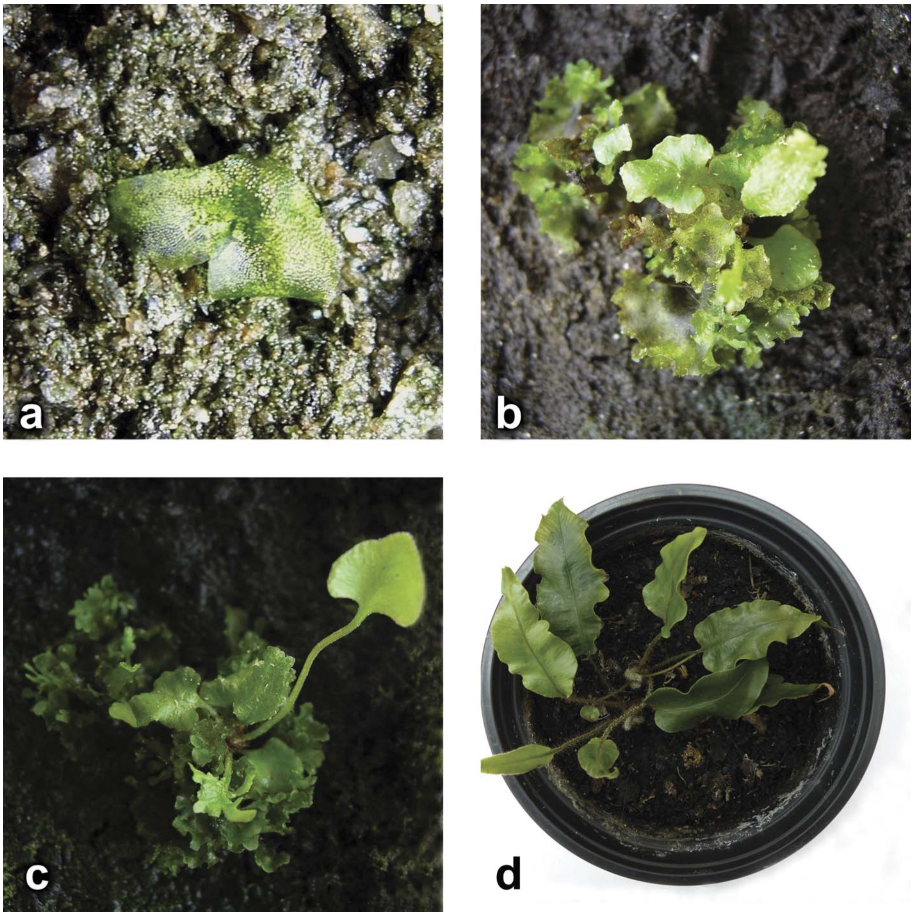

Fig. 1. Developmental morphology of *Elaphoglossum hybridum*. **a.** Bi-lobed prothallus six months after it first appeared on the cultured cryoconite soil sampled from the Signy Island ice cap (July 2000). **b.** Prothallus with leaf beginning to develop at upper centre (January 2003). **c.** Development of leaf and elongation of petiole (December 2003). **d.** Mature plant of *Elaphoglossum hybridum* (June 2011).

the foliose liverworts *Barbilophozia hatcheri* (Evans) Loeske and *Cephaloziella varians* (Gottsche) Steph.). After around two months, several other local mosses appeared (*Bryum* sp., *Encalypta rhaptocarpa* Schwaegr., *Hennediella antarctica* (Ångstr.) Ochyra & Matteri, *Polytrichastrum alpinum* (Hedw.) G.L. Sm., and *Sanionia uncinata* (Hedw.) Loeske), as well as a green multicellular disc about 2 mm in diameter. This was tentatively ascribed to the thalloid liverwort *Marchantia berteroana* Lehm. & Lindenb., a frequent species on Signy Island, where it is not fertile but does produce copious vegetative gemmae. This phase of culturing was terminated after four months when the dishes were transported by ship at 4°C to the British Antarctic Survey, Cambridge, and maintained at that temperature in a controlled environment chamber (Foster Refrigeration, Kings Lynn) for a further three years.

Development of the gametophyte

The thalloid plant gradually became bi-lobed and grew to about 6 mm in diameter after six months (July 2000) (Fig. 1a), by then clearly identifiable as a fern prothallus (gametophyte). After 15 months (April 2001), the prothallus was transplanted onto a sterilized (48 hr at 50°C), homogenized moss peat substrate, prepared at Signy Island. By September 2001, the gametophyte had increased to *c*. 15 mm diameter and had become multi-lobed and deeply crenellated, and the ventral surface had developed clusters of rhizoids. By January 2003, several of the lobes had developed into small ovoid entire leaves with a very short stem or rachis (Fig. 1b) which, by December 2003, had become rhomboid in shape with a cuneate base and borne on a short stem, both elongating to *c*. 3.0–5.0 cm length (Fig. 1c). The dish was moved to room temperature (*c*. 15–20°C) and the growth rate accelerated. The plant survived two further transplants into larger containers. By 2009, the plant was mature and, between then and present, the lanceolate leaf dimensions have ranged from 5.0–10.0 cm long by 2.0–4.5 cm wide, borne on petioles of 5.0–7.5 cm long (Fig. 1d), with a few dying annually and being replaced by new leaves. The leaf margins and petioles are densely covered with rust-brown hairs. No sporangia have developed.

Identification and provenance of the Signy Island fern

In 2012, photographs and two fronds of the Signy fern were sent to the Natural History Museum, London, for identification. This has been confirmed as *Elaphoglossum hybridum* (Bory) Brack. (Lomariopsidaceae), a species with a southern African distribution centred on South Africa (notably the high eastern Cape, central, tropical and east Africa), Madagascar and the Mascarene Islands in the southern Indian Ocean, as well as Tristan da Cunha and Gough Island in the south Atlantic Ocean (Crouch *et al*. 2011).

Discussion

Pteridophytes are unknown in the contemporary Antarctic flora although transplant experiments have proved that fern species from the Falkland Islands and South Georgia are capable of surviving at least one winter in Antarctic environments (Holdgate 1964, Edwards 1979). However, aerobiological studies conducted at Signy Island and King George Island, South Shetland Islands, have shown that the sporomorpha 'rain' contains fern spores (e.g. Churchill 1973 p. 80–81, Kappen & Straka 1988, Smith 1991, Chalmers *et al*. 1996), although their viability was not tested.

This is the first record of a pteridophyte cultured from an Antarctic substrate, although it cannot be construed as a component of the native flora. Nevertheless, it provides evidence that viable spores of ferns, like those of bryophytes and fungi, do reach remote Antarctic sites (Smith 1991, 1993, Lewis Smith & Ochyra 2006), some of which may be considered as potential colonists, if and when growing conditions become favourable.

All locations from where *Elaphoglossum hybridum* is known are well to the north and east of the South Orkney Islands, which lie in the path of strong westerly prevailing winds. The most probable explanation for the spore, from which the present plant developed, reaching Signy Island was by encircling the Southern Hemisphere on an east–west trajectory at high altitude. How it was transported into the upper atmosphere is open to speculation. However, once such sporomorpha have been carried to high altitude they may be transported across great distances by upper air currents (e.g. Van Zanten 1978, Linskens *et al*. 1993, Muñoz *et al*. 2004).

Elaphoglossum hybridum is closely related to *E. randii* Alston & Schelpe, a species endemic to Marion Island and Iles Kerguelen in the southern Indian Ocean. Furthermore, the present author reported an unsubstantiated observation of a fern fitting the description of *E. randii*, occurring at *c*. 300 m amongst scree on Mount Hodges, above King Edward Cove on South Georgia, but was unable to locate the plant himself, and therefore could not confirm its identity (discussion in Massé *et al*. 1982).

Cryoconite holes in ice surfaces tend to concentrate detritus as the ice melts. This study has shown that such mineral detritus contains viable plant diaspores which are capable of germinating when subjected to favourable growing conditions. Soil culture experiments from a number of Antarctic locations have produced a diversity of bryophyte species typical of the local flora. Also, at Signy Island, such experiments have yielded two moss and a basidiomycete fungus species unknown in the Antarctic (Smith 1993). Furthermore, Lewis Smith & Ochyra (2006) described an exotic moss (*Entosthodon* cf. *subnudus* (Taylor) Fife) cultured from high altitude soil on Coulman Island, in the Ross Sea, Continental Antarctica. The present author (unpublished) also cultured basidiocarps of the fungus *Leptoglossum retirugum* var. *antarcticum* (E. Horak) Garrido from the moss *Ceratodon purpureus* sampled in Wilkes Land, Continental Antarctica, a taxon previously known only from the Maritime Antarctic (Pegler *et al*. 1980).

These simple experiments provide evidence of what must be an abundant pool of viable propagules preserved in various substrata throughout the Antarctic biome. Lewis Smith (Smith 1991, 1993) discussed the importance and dynamics of such diaspores trapped in and on Antarctic ice caps, glaciers, soils and moss, and of the role of atmospheric transport over great distances. With the current trend in regional warming in the Maritime Antarctic (e.g. Smith 1990, Convey 2003), there is an increasing probability that exotic propagules in the soil, previously unable to develop into plants because of adverse growing conditions, will be able to become established.

Depending on their longevity, if exotic propagules ultimately find their way to lowland ice-free areas, by wind or in meltwater, where there is a favourable microclimate for growth, they may succeed in establishing populations of species, and even of phyla, as yet unrepresented in the biome. If some are capable of retaining their viability in a state of cryopreservation, it may be possible for them to survive glacial epochs. If this can be proved, for example by culturing debris embedded in known-age ice from cores, then it is preservation of diaspores in ice (and their subsequent germination) that may be the principal means by which species survive glaciations rather than as actual plants persisting in ice-free refugia, as is usually proposed (e.g. Lewis Smith & Ochyra, 2006, Convey *et al*. 2008, Ochyra *et al*. 2008 p. 50–52).

More sophisticated sampling, especially from particulate matter in ice cores and lake sediments, coupled with carefully controlled culturing techniques, could yield important information regarding the longevity of viable cryopreserved propagules and their potential to become colonists if and when they reach suitable habitats with favourable developmental conditions.

Acknowledgements

I am indebted to Fred Rumsey and Harald Schneider, Natural History Museum, London, for providing the identity of the Signy fern. I am also grateful to Peter Convey and an anonymous reviewer for constructive comments on this paper. Part of this work was undertaken during the tenure of a Leverhulme Emeritus Fellowship at the British Antarctic Survey, Cambridge.

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