Conservation issues for Antarctic fungi

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Abstract. More than 1,000 species of fungi have been reported from the Antarctic and sub-Antarctic region. Most are species known from elsewhere in the world, particularly from cool temperate and alpine habitats: few are considered truly endemic to the Antarctic region. Several legislative mechanisms are available that could be used to protect or conserve the Antarctic mycota. These include national legislation within the sub-Antarctic islands, and the Measures and Decisions of the Antarctic Treaty Consultative Meeting which have jurisdiction within the Antarctic Treaty area south of latitude 60° S.

Key words: Antarctic fungi, Antarctic region, conservation

The Antarctic region

There have been various definitions of the 'Antarctic region' based on geographical, political and physical criteria. In broader mycological surveys the Antarctic has been defined as the peninsular and continental Antarctic, together with the islands of the Scotia Arc (see Pegler *et al.* 1980; Bridge *et al.* 2010), while the 'Antarctic region' also includes the sub-Antarctic islands. In the political context, the Antarctic Treaty applies to the area south of latitude 60° S. The sub-Antarctic is less clearly defined but a working description that has been used in mycological studies is the area between the Polar Front (an upwelling formed where the cold water from the Antarctic largely sinks beneath warmer water of the South Atlantic and southern Indian and Pacific oceans) southwards to latitude 60° S. This area will vary but has been taken to include South Georgia, Bouvetøya, the Prince Edward Islands, Iles Crozet, Iles Kerguelen, the Heard and McDonald Islands and Macquarie Island (Pegler *et al.* 1980; Bridge *et al.* 2010).

Antarctic fungi

The earliest records of fungi from the broad Antarctic region date from the middle of the 19th century (e.g. Berkeley 1847), and the first record from the Antarctic mainland is of *Sclerotium antarcticum* E. Bommer & M. Rousseau (= *Sclerotinia antarctica* Gamundi & Spinedi) collected in 1898 from Danco Land, today known as the Danco Coast (Bommer & Rousseau 1905; Gamundi & Spinedi 1987). Since those early reports there have been around 200 publications about fungi of the region, and currently some 1,000 species of fungi have been recorded from either the Antarctic or the defined sub-Antarctic area, with some 500 recorded from south of 60° S (Onofri *et al.* 2007; Bridge *et al.* 2008, 2010). These records have been collated and referenced in a single publically available database (Bridge *et al.* 2010). Most relate to fungi which are either cosmopolitan, or also known from other parts of the world, and currently only around 2–3 % of the fungi recorded are considered to be truly endemic and even these may be in doubt or classified as endemic due to lack of baseline surveys elsewhere (Onofri *et al.* 2005; Bridge *et al.* 2008).

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General biodiversity

The overall biodiversity of the Antarctic region is low relative to other areas of the world. There are, for example, no trees, and while there are some woody shrubs on certain sub-Antarctic islands, the flora of the true Antarctic is limited to two vascular plants (*Deschampsia antarctica* and *Colobanthus quitensis*) and a restricted range of cryptogams including mosses, the algal components of lichens, and liverworts. The terrestrial fauna is limited to invertebrates, with microarthropods predominating and only two 'higher' insect species present in areas of the northern Antarctic Peninsula (Block 1984).

Fungal diversity

As could be expected, fungal associates of plants and animals are restricted by the absence of their associated organisms. Larger fungi are rare in the true Antarctic, although there are some isolated reports from the northern Antarctic Peninsula (in the maritime Antarctic biogeographic zone; e.g. Gamundí & Spinedi 1988; Bridge *et al.* 2008). They are, however, relatively common on the sub-Antarctic islands such as South Georgia and Kerguelen (e.g. Smith 1994). There are few larger basidiomycetes, although larger ascomycete genera such as *Lamprospora* and *Octospora*, which are typically associated with mosses elsewhere, are also found with mosses in the Antarctic (Pegler *et al.* 1980). Despite this, representatives of all of the major taxonomic groups of fungi are present in the region, and recent molecular studies have suggested that zygomycetes and chytrids could be much more frequent than current culture based sampling suggests (Lawley *et al.* 2004; Bridge & Newsham 2009). Examples of common soil fungal genera include: *Acremonium, Cladosporium, Chrysosporium, Geomyces, Penicillium, Phoma, Mortierella, Mucor, Trichoderma* and *Verticillium.*

There are few reports of marine fungi from the region. Fell and others isolated a number of basidiomycetous yeasts from Antarctic marine samples (e.g. Fell & Statzell 1971; Fell *et al.* 1973), and several chytrid groups have been observed (Bahnweg & Sparrow 1972, 1974). A preliminary account of Antarctic marine fungi was produced in 1986 (Pugh & Jones 1986), and since then there has been some work using wood baits (e.g. Grasso *et al.* 1997). Most recently Loque *et al.* (2010) identified several filamentous fungi and yeasts including *Antarctomyces, Aureobasidium, Cryptococcus, Geomyces, Leucosporidium, Metschnikowia, Oidiodendron, Penicillium, Phaeosphaeria* and *Rhodotorula* associated with Antarctic marine macroalgae from genera.

Conservation procedures

The Antarctic region is increasingly at risk from human impacts, particularly around research stations or areas of significant human activity. Impacts may include chemical pollution, sewage contamination, disturbance of indigenous animals, destruction of habitats and the introduction of non-native species (Tin *et al.* 2009). The physical and political arrangements in the Antarctic region mean that several different conservation strategies and types of legislation are in place. Sub-Antarctic islands are governed under national jurisdiction, generally as dependencies, or discrete self-governing territories with conservation requirements and mechanisms based on those of the sovereign nation. South Georgia, for example, is protected under the Falkland Island Dependencies Conservation Ordinance (1975), the French sub-Antarctic islands are incorporated into the Réserve Naturelle National des Terres Australes Françaises (2006) while of the Australian islands, Macquarie Island is designated as Macquarie Island Nature Reserve (1978) and the Heard and McDonald Islands are protected under the Heard Island and McDonald Islands Act (1953).

None of these conservation measures are directed specifically at fungi, although legislation aimed at protecting unique sub-Antarctic habitats are in place. Most islands have a high level of protection under national jurisdiction, but some have additional status under international agreements such as the United Nations Educational, Scientific and Cultural Organisation [**UNESCO**] World Heritage Convention (1972); for example Macquarie Island, and the Heard and McDonald Islands are UNESCO World Heritage Sites, with the Prince Edward Islands currently under consideration for World Heritage Site listing. The Prince Edward Islands are also classified as containing Wetlands of International Importance under the Ramsar Convention (see www.ramsar.org). Within the sub-Antarctic, Macquarie Island Marine Park (1999), the Heard Island and McDonald Islands [**HIMI**] Marine Reserve (2002) and the Prince Edward Islands Marine Protected Area (2009) protect ocean areas.

All human activity on land, ice and sea, south of latitude 60° S is governed through the Antarctic Treaty System (see www.ats.aq) with the Committee for Environmental Protection [**CEP**] providing advice on environmental and conservation issues to the Antarctic Treaty Consultative Meeting [**ATCM**]. Decisions taken there must be agreed through consensus by the 28 Consultative Parties that represent around two thirds of the Earth's population. The Protocol on Environmental Protection to the Antarctic Treaty (also known as the Environmental Protocol or Madrid Protocol; signed in 1991, and which came into force in 1998) is the main instrument concerned with conservation and management of biodiversity. This designates the entire Antarctic Treaty Area as a '*natural reserve, devoted to peace and science*" (Article 2)'. The Protocol contains several annexes, including Annex I: Environmental Impact Assessment (which requires the environmental impacts of all proposed activities to be considered before their commencement), Annex II: Conservation of Antarctic Fauna and Flora (which protects the indigenous flora and fauna and prohibits the intentional introduction of non-native species – and specifically soil and micro-organisms) and Annex V: Area Protection and Management (which allows any area, including any marine area, to be designated as an Antarctic Specially Protected Area [**ASPA**]). Annex V, Article 3.1 specifies that **ASPA**s may be designated to: '*protect outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research*'. Activities in the Antarctic are carried out under permits that are administered by the different Treaty nations. As a result, all biological sampling is made under some degree of regulation.

The Convention on the Conservation of Antarctic Marine Living Resources [**CCAMLR**] regulates the exploitation of mainly fish and krill stock south of the Polar Front, but both **CCAMLR** and the Environmental Protocol provide mechanisms for protection of marine areas.

To date there have not been any direct attempts to conserve Antarctic fungi. Historic expedition huts have been conserved, and in some cases this has highlighted the presence of wood-degrading fungi (Blanchette *et al.* 2004). It is currently unclear what proportion of Antarctic fungi are unique to the region, and only some 20–30 species are considered likely to be geographically restricted (Onofri *et al.* 2005; Bridge *et al.* 2008). However, many of the fungi recorded to date have also been found in other cold environments, and it is likely that the broad environmental conditions rather than the geographic region are more relevant to conservation efforts. Specific geographic areas within the Antarctic Treaty area can be designated as **ASPA**s under Annex V of the Environmental Protocol for particular environmental protection (similar to Sites of Special Scientific Interest in the UK), but this has always been done on the basis of the total biological assemblage or the uniqueness of the ecosystem.

A major concern within the **CEP** is the risk to Antarctica associated with unintentional introduction of non-native species from outside the region. In the sub-Antarctic Islands, since the first arrival of humans in the late 1700s there have been over 200 non-native species introductions, with invasive species causing dramatic impacts upon the existing ecosystems (Frenot *et al.* 2005). Introduced biological groups include plants (c. 62 dicotyledons and c. 45 monocotyledon), vertebrates (cattle, fish, mice, rabbits rats, reindeer and sheep) and invertebrates (over 100 species including aphids, beetles, flies, moths, slugs, spiders, springtails and worms). There are, however, many difficulties associated with the unambiguous identification of non-native fungi, and little research has been done on their impacts on sub-Antarctic ecosystems. One of the few examples is from Marion Island where the non-native *Botryotinia fuckeliana* (conidial state: *Botrytis cinerea*) now infects entire stands of the Kerguelen cabbage (*Pringlea antiscorbutica*), and was probably transferred to the island on fresh vegetables (Kloppers & Smith 1998). Rats have had devastating impacts on native nesting bird populations and rabbits and reindeer have had major impacts on the vegetation; however, our understanding of how these changes have impacted upon indigenous fungal populations is very limited.

By comparison, the Antarctic has only four proven non-natives species introductions: two invertebrates and two plants (Hughes & Convey 2010). These were discussed by Hughes & Worland (2010). The introduction of non-native fungal strains since the well-known expeditions of the 'heroic age' of exploration is, however, almost a certainty (e.g. Hughes *et al.* 2010). Introduction of non-native fungi is a little studied but genuine risk to Antarctic ecosystems in terms of competing with indigenous species, altering existing nutrient cycling or causing disease in native plants, birds, seals and invertebrates. The Environmental Protocol permits the discharge of sewage from coastal Antarctic research stations into the marine environment, which may contain yeast and fungi of human origin (Hughes 2004). Line (1988) reported the likely introduction of the *Hormoconis resinae* state of *Amorphotheca resinae* to fuel contaminated soil around Mawson Station on the coast of continental East Antarctica, while *Phialophora fastigiata* may have been introduced to the area around Casey Station by association with imported softwood packing cases (Bölter *et al.* 2002). The difficulty of determining whether a fungal species has been introduced is illustrated by *Aspergillus fumigatus*, which can cause aspergillosis in bird populations. This species was isolated from soil near Adelie penguin colonies at Cape Hallet (Victoria Land) and it was reported that it may have been introduced in association with human activities at a nearby research station (Wicklow 1968). This species had previously been reported from air sampling at a different Antarctic research station (Corte & Daglio 1964), and has also been detected in soil in a remote dry valley (Baublis *et al.* 1991).

Conclusion

There are clear legislative and administrative mechanisms available that allow for conservation of Antarctic fungi. It is, however, more difficult to determine the scientific merits of any conservation activity. Although all of the fungi so far identified from the region have been documented, this record is based on rather few studies (*ca* 200+) from a very small proportion of the continent. It is therefore very difficult to place the available information within broad ecological and biogeographical contexts. This situation is further complicated by the results from recent molecular studies which indicate that many fungi not known from the continent through culture or isolation can be readily detected by molecular methods. Given these constraints it would appear reasonable to recommend that conservation attempts could be most usefully directed to preserving sites and ecosystems, on the supposition that this may aid in conserving the largely unknown fungal diversity present within them.

Wherever humans visit, they tend to have direct environmental impacts including (1) homogenization (genetic dilution) of the local biota through human-mediated transfer of native species, (2) introduction of non-native species, (3) irreversible contamination of sites by human-associated (commensal) microbiota, (4) chemical pollution and (5) direct physical impacts at sites of concentrated activity. Few areas of the terrestrial environment on Earth are known unequivocally to be free of all human visitation. However, some such areas do exist in Antarctica and contain pristine biological communities free of all local human impacts. These communities are of immense value for future scientific research. Given the likely advances in molecular, proteomic and biochemical techniques in the coming decades, it is essential that the practicalities of designating 'inviolate' areas should be re-examined, so that future scientists will have these pristine communities in which to apply their advanced techniques. In a continent where the biota is dominated by kingdoms other than those of animals and plants, the balance of conservation and protection efforts should, perhaps, be shifted away from charismatic species such as penguins and seals, towards this diverse range of other biological communities resident in Antarctica.

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