Non-native microbial introductions: what risk to Antarctic ecosystems?

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Brief Overview

Antarctica's biodiversity and its intrinsic values are potentially at risk from the introduction of non-native species, derived from a range of sources including human activities. Whilst controls on introducing plants and invertebrates are now in place, limited attention has so far been given to microorganisms that comprise the majority of the Antarctic terrestrial biomass, and are highly dispersive. Information deficits and likely impacts in a warming climate indicate that this should be given a higher research priority, particularly in ice-free areas where the range of microbial habitats for colonisation is higher.

Detailed Overview

Microorganisms, including bacteria, archaea, algae, fungi, viruses and microeukaryotes, generally comprise the majority of the biomass and biodiversity in Antarctic terrestrial and freshwater ecosystems, particularly in climatically extreme habitats where higher organisms cannot survive[1]. Soil gradients and chemistry, different geological substrates, wind patterns and precipitation events interact in complex ways to provide a mosaic of specialised communities across the continent[2]. The relative simplicity of Antarctic terrestrial ecosystems makes them of substantial scientific value in understanding more complex systems found in other areas of the world. Molecular biology techniques have shown the presence of numerous endemic species in Antarctica (see, for example 3) which are a potential source of novel genes, gene products and compounds[4]. Here we consider both the relevance of, and the practical issues relating to the importance of future prevention of microbial introductions or redistribution of microorganisms within Antarctica.

Microbial invaders: the state of knowledge

Non-indigenous microorganisms, along with spores and other propagules, attached to dust particles and aerosols, are constantly seeded into Antarctic continental (and marine) systems[5, 6]. Movement of animal species, including humans, into Antarctica and the sub-Antarctic zone can facilitate the transport of microorganisms from lower latitudes[7]. A review of Antarctic photoautotroph biogeography concluded that whilst climate change was eroding physical dispersal barriers for plants to Antarctica, temporal, microclimatic and evolutionary drivers remained strong limitations on invasive colonisation by photoautotrophic bacteria and algae[8]. Excluding humans, these mechanisms have, presumably, been active through the lifespan of the continent in its polar position, varying with changing macroclimatic conditions.

Over the past century increasing human presence on the continent and in the surrounding oceans has supplemented, to a completely unquantified extent, the transport of non-indigenous microorganisms into the Antarctic region. Release of untreated sewage, with associated non-indigenous microorganisms, is a source of introductions into marine environments around some Antarctic research stations, while human waste still persists at some coastal and inland locations[9, 10, 11]. In addition, molecular biological studies of airborne transportation of microorganisms showed potential dispersal of a range of human-associated microorganisms from an isolated Antarctic research station[12], and scientific activities inevitably disseminate human-borne microorganisms into remote areas, purely from the presence of humans[13].

No reliable quantitative data are yet available on either 'natural' or anthropogenic rates of microbial input to the Antarctic continent or its surrounds. An initial attempt to quantify the effects of individual human activities[13] was rudimentary, but did suggest that human activities at localised high impact sites (such as field camps in ice-free areas) might input non-indigenous cellular material of the same order as the standing indigenous microbial biomass. The consequences of such contamination are poorly understood, but may result in enduring molecular signals associated with non-indigenous microorganisms.

Anthropogenic transport mechanisms; inter – and intracontinental

Soils may act as a source of a diverse range of microorganisms and the introduction and movement of soils between ice-free areas may result in the translocation of microorganisms. Under the Protocol on Environmental Protection to the Antarctic Treaty (Annex II Conservation of Fauna and Flora) the importation of non-sterile soil is to be avoided to the maximum extent practicable and steps should be taken to prevent non-native microbial introductions. Nevertheless, non-Antarctic soils may be introduced inadvertently in association with imported root vegetables for human consumption and with cargo or equipment[14, 15]. Earlier introduction of non-Antarctic soils for transplantation experiments and horticultural use has resulted in the establishment of plant and invertebrate species at some sites, and it is likely that non-native microorganisms were introduced concurrently[16].

Distinct Antarctic biogeographic regions have been identified for macroscopic species and there is evidence for similar or greater geographical differences in biodiversity for microorganisms[17]. Levels of microbial exchange between distinct locations have not been quantified, but areas of extensive continuous ice-free soils, such as the McMurdo Dry Valleys, may be at particular risk[11]. The ever-increasing human footprint in Antarctica means that the number of locations known to be pristine habitats, where increasingly sophisticated cutting-edge research techniques may be used to their full potential, will continue to decline[4].

While local dispersion of microorganisms is mainly linked to stochastic dust storm events, more back-trajectory wind analyses, coupled with massive sequencing of aerosol bacterial communities across much wider altitudinal ranges, are needed to improve our understanding of the qualitative and quantitative nature of inter- and intra-continental transport mechanisms[6].

The Risks

A lack of research makes it difficult to predict the impacts or quantify the risks of non-native microorganism introductions. Nevertheless, there are three key areas of concern:

1) Introduction of new and aggressive species could result in changes in the microbial community structure and loss of significant biodiversity (although most introduced lower latitude species are unlikely to function efficiently under the current Antarctic climate conditions).

2) The disruption of the microbial web could result in irreversible changes to biogeochemical pathways with consequences for nutrient cycling and ecosystem services[18].

3) Introductions of antibiotic resistance genes could have unforeseen consequences whilst introduced pathogenic microorganisms may cause disease in wildlife, but little is known about rates of disease-causing microorganisms via natural routes such as vagrant birds[7].

As yet, very little is known about microbial introductions into surface freshwater or marine environments, although the development of methods to prevent introductions of microorganisms into sub-glacial water bodies has received substantial attention e.g. SCAR's Code of Conduct for the Exploration and Research of Subglacial Aquatic Environments[19].

There are some obvious possible mitigation steps, but they would be difficult to introduce. The impacts of human activity could be substantially mitigated by stringent biosecurity measures (such as the compulsory wearing of environmental suits for tourists and terrestrial Antarctic researchers, for example), as recommended in some specific locations and circumstances in the SCAR Code of Conduct for Activity within Terrestrial Geothermal Environments in Antarctica (ATCM XXXIX WP23). Apart from very specific sites, this seems unlikely to prove acceptable or practicable. The principal reason for caution at present, however, is that there are no data for the relative inputs of non-indigenous microbiota from 'natural' processes and from anthropogenic activities, either in qualitative (which organisms?) or quantitative (how many?) terms. If the former are orders of magnitude greater than the latter, then mitigation of anthropogenic inputs might be irrelevant.

As in other fields, data are urgently required on (i) the exact mechanisms of non-indigenous microbial inputs into Antarctic ecosystems and (ii) the rate values for these inputs. Only with these data will a rigorous assessment of the importance of the problem be determined. The recently formed SCAR Group "Aerobiology over Antarctica" aims to produce a pan-continental dynamic aerobiological map which, if supported by biomass quantification, would allow realistic input rates of airborne microbes to Antarctic environments to be calculated[20].

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