Microscopic life on the frozen continent

Don Cowan tells us about the terrestrial microbes of Antarctica, and an exciting new research programme

The McMurdo Dry Valleys of Antarctica represent one of the most extreme environments on Earth. Temperatures might rise a little above 0°C for a few months during the summer 24-hour daylight period, but water is always scarce. In winter, when the sun never rises for three months, soil temperatures can plummet to −60°C. It is perhaps surprising that anything can survive these conditions, but research by our team at the University of Pretoria's Centre for Microbial Ecology and Genomics has shown that a wide diversity of soil microorganisms thrives here.

Prof. Cowan collecting samples in the Antarctic Dry Valleys area.

The most active and complex terrestrial soil microbial communities exist in protected niche habitats, either inside or underneath transparent rocks. These endo- (inside) and hypo- (underneath) lithic communities are biodiversity and functional 'hotspots' in otherwise low-biomass environments. They are dominated by photosynthetic cyanobacteria (also known as blue-green algae), which provide carbon, nitrogen and energy to non-photosynthetic, or heterotrophic, members of the microbial community. Heterotrophs in the lithic communities include many species of bacteria, fungi and even algae and archaea.

These communities only exist because the overlying quartz rock allows enough light to pass through to support cyanobacterial photosynthesis, while protecting the entire microbial community from destructive environmental conditions, particularly extreme desiccation and harmful UV radiation. Interestingly, there is no temperature advantage in these lithic habitats; the organisms have evolved to metabolise at low temperatures and to survive the effects of freezing.

Two very interesting and very different mechanisms have evolved for the protection of cells from freeze damage: special ice-nucleation proteins in the cytoplasm trigger the rapid crystallisation of water into very small ice crystals that do not puncture cell membranes, and biosynthesis pathways redirect stored carbon in the cell to synthesise and accumulate compatible solutes (sugars and sugar alcohols), which depress the freezing point of water in the cytoplasm.

Over two decades, my Antarctic terrestrial studies have focused on many aspects of the microbiology, ecology, function and adaptation of microorganisms in Antarctic soils, but they essentially aim to answer the following key questions:

- what is there (diversity)?
- what is it doing (functionality)?
- how does it survive (adaptation)?
- how does it respond to change (resilience and evolution)?

These studies are principally funded by the National Research Foundation through the South African National Antarctic Programme (SANAP). The most recent three-year tranche of funding, which started in 2017, supported research that represented another step forward in our ongoing investigations of extreme microbiology. The focus was on adaptation and community structural and functional resilience, the latter being at the forefront of the minds of the world's ecologists, since climate change patterns have already resulted in significant warming trends across much of coastal and maritime Antarctica. The way in which sensitive, specialised and unique Antarctic biological communities may respond to climatic changes is currently unknown, and is cause for concern amongst the Antarctic conservation community.

Environmental samples collected from the Antarctic Dry Valleys during a 2018 field expedition are being used in a series of experiments, based on next-generation sequencing technologies that allow for rapid sequencing of the nucleic acids, DNA and RNA. The study of a collection of genetic material from a mixed community of organisms, as found in our environmental samples, is termed metagenomics, and it enables us to investigate genome evolution, functional capacity and metabolic resilience in Antarctic soil microbial communities.

My involvement as an international collaborator in a new Australian-led research programme also brings exciting opportunities for the Centre for Microbial Ecology and Genomics team. In April 2020 the Australian government awarded Aus$36 million to Monash University for the programme, called 'Securing Antarctica's Environmental Future' (SAEF), which will include participants from some 30 organisations in Australia and abroad. The programme leader, ex-South African Professor Steven Chown, is a world-renowned ecologist and is the current President of the Scientific Committee on Antarctic Research – the leading international body facilitating research in, from and about Antarctica.

The focus of the SAEF programme is on the future conservation of Antarctica, which is experiencing rapid climate change, with warming marine waters and melting terrestrial glaciers. The implications of climate change go far beyond the continent itself, with potentially serious global impacts such as a rise in sea levels and changes in ocean productivity. The programme objectives include surveys of species diversity – from microorganisms to higher eukaryotes – across the Antarctic continental and sub-Antarctic zones, to investigate their biogeographical distributions, and to assemble the data to inform future regional conservation strategies. One of the core outcomes of the programme is the development of effective environmental stewardship strategies to secure Antarctica into the future as a natural reserve.

Hypolithic cyanobacteria-dominated microbial communities, like this one on the underside of a quartz pebble, are often referred to as the 'tropical rainforests of the Antarctic deserts'.

A green layer inside a rock is evidence of an endolithic microbial community supported by photosynthetic cyanobacteria.

In parallel, the SAEF programme will study trends in human activity in the Antarctic regions, particularly the growing tourism industry, as a major factor in future regional conservation strategies and policies. Tourism brings hundreds of thousands of visitors to the continent annually, and although well controlled at present, uncontrolled tourism has the potential to directly or indirectly damage sensitive Antarctic biological communities – for example, by physical disturbance, contamination, or the introduction of non-indigenous species that may outcompete the local species. Managing Antarctic tourism, for the benefit of both the tourists and the continent, is therefore an important future strategic objective.

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The desert sands of the Victoria Valley in East Antarctica.