PCAS 16 (2013/2014)

Critical Literature Review
(ANTA602)

What are the limiting survival factors of microbial life in continental terrestrial Antarctica?

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Word count: 2844

Abstract (ca. 200 words):

Despite the extreme conditions of inland terrestrial Antarctica, life still manages to survive in microbial form.
Exploring and understanding how it exists has important implications in understanding evolutionary processes, modelling early earth life and astrobiology.

The most extreme environments that harbour microbial life in continental Antarctica are the Dry Valleys of the Transantarctic Mountains and the protruding Nunataks of the Ice sheet expanse. Conditions in these environments are harsh, with water in low supply, extreme temperature variation and either too much or too little sunlight.
Life exists in a variety of shapes and forms. Nematodes and Tardigrades are some of the hardiest micro fauna known, able to survive total desiccation and freezing. Mosses, Algae and Lichen make up the photosynthesis capable organisms and can survive in a wide variety of environments.
These organisms strive against the odds and form habitats not just in soil or on rock surfaces, but also under or within the rock. This helps to manage their moisture supply, and protect from harmful exterior forces such as extreme temperature variations and UV radiation.
The major limiting forces for microbial life in terrestrial continental Antarctica are varied. Unsurprisingly water availability is the most important as it controls all organisms ability to live and grow. Temperature is also important due to its effect on the freezing point of water and controls on photosynthesis. Light plays a major part as it helps control the growth of the photosynthetic organisms as well as varies the temperature. Surface type is also important due to the slow growth rates in Antarctica, coupled with the environments required in which to survive.

Introduction

Why is Antarctic microbial life important?

Antarctica is well regarded as being one of the most extreme environments on our planet. It is widely understood that it is the highest, driest, windiest and coldest continent in the world. However what is not known so much is the extent that life can exist to, even under these harsh seemingly inhospitable conditions.

Although the charismatic larger wildlife such as penguins and seals take the majority of people's attention, they are really part of the marine ecosystem. Antarctica has no established land based larger creatures, however this does not make it devoid of life. Throughout refuges in the continent are diverse habitats of microbial life, seemingly existing in areas it was thought impossible for life to survive in.

These microbes can provide us with important information that can be used for many purposes. This includes increased information on mapping evolutionary processes, modelling the history of life in early earth as well as many implications in astrobiology.[1]

Due to the harsh environments in the rest of the solar system, it is likely that if life is discovered somewhere outside of earth, it will be similar to the Antarctic microbial organisms that exist on the fringes of life as we know it. From the dry windswept deserts of Mars to the sub glacial Oceans of Europa. Antarctica provides us with a very real snapshot of what life could be like on other worlds.

In order to comprehend this we need to understand what life exists in this harsh climate and what it is that limits the ability of life to survive in these extreme conditions.

Typical climates across Continental Antarctica

Terrestrial Antarctica is dominated by glacial ice sheets. This leaves only roughly 0.4% of continental Antarctica ice free and available for habitation[2]. Of these ice free zones, the most extreme are that of the Dry Valleys in the Transantarctic Mountains, and the Nunataks (mountainous peaks that jut out from the ice sheet) which are scattered across the East and West continental Antarctic ice sheets.

Dry Valleys

Considered one of the most inhospitable zones on our planet, the Antarctic Dry Valleys are often likened to those of Mars. The largest and most studied of these are in the Ross sea region, covering an area of around 4800km^2 [3].

Although visually barren and devoid of life the Dry Valleys are home to a surprising amount of microorganisms. These occupy some of the less arid soils in the valleys, as well as living within the Beacon Sandstone high up in the mountainous terraces[3].

The fact that life exists in these valleys is remarkable, as annual precipitation is less than 100mm, the driest desert in the world[3]. Mean annual temperatures sit at around -20°C across all the Dry Valleys with some ranging between -15°C and -30°C[2]. To top this off due to their location near the south pole, the Dry Valleys receive only 6months of light per year, as well as consistent Katabatic flows[2].

The Katabatic flows are strong gravity powered winds that race across the Antarctic ice sheets draining down the Dry Valleys towards the sea. These winds are extremely desiccating, picking up moisture as they flow down the valleys and taking it out towards the ocean[3].

Surfaces in the valleys are subject to very large temperature fluctuations throughout the year. During summer, temperatures can exceed 0°C, increasing the potential availability of liquid water. Maximum temperatures of the surface can rise above 17°C and fluctuate by more than 20°C on a daily scale. This can result in multiple instances of freezing and thawing in a single day. During winter, temperatures can range from -40°C to -60°C. [2]

Although the mineral soils of the valleys are exceptionally dry, with comparable water content to many of the world's hottest deserts (<2% mass water content)[2]. Large water reservoirs are present within the soil. This occurs either as ice-cemented soil or larger buried chunks of ice. The permafrost layer also exists within 30cm of the surface[2]. This can result in a wetted zone occurring between the permafrost layer and the surface. At depths of 5-10cm this wetted zone provides the most active soil layer for biota[2].

Nunataks

Nunataks are some of the highest altitude places in Antarctica. Representing the peaks of mountains buried in 2-3km of ice, these isolated outcrops provide a contrast to the otherwise icy landscape of inland Antarctica. Due to Nunataks being more widespread across the Antarctic continent, as well as being more isolated then the dry valleys, climate data is more difficult to come by. However the La Gorce Mountain Nunataks have average summer temperatures of -14°C[4]. Some typical winter temperatures at these latitudes and altitudes (85°S, 2000+m) are as low as -70°C.

What kinds of life?

Everyone knows of the penguins, seals and other marine wildlife that inhabit the fringes of the frozen continent. However even these superbly adapted animals cannot survive in the Antarctic inland. This domain falls exclusively to various hardy microorganisms, which can survive in conditions thought impossible for most of Antarctica's human history.

The extreme microorganisms inhabiting terrestrial continental Antarctica can be classified into existing in four distinct communities. Chasmoliths (species inhabiting cracks in rocks), Endoliths (species inhabiting rock interiors), Hypoliths (species that live under rocks), and Bulk soil inhabitants (soil inhabiting species) [2, 5]. Within these communities a diversity of 16 types of phyla exist such as: Cyanobacteria, Fungi, Algae, Lichens, Nematodes, Tardigrades, Rotifers, Springtails and Mites[5, 6].

Nematodes

Nematodes are some of the larger organisms. They are small worm like creatures and an adult Nematode can range from 0.3mm to over 8m in length[7]. However in Antarctica they tend to remain small(less than 1mm) due to the inhospitable environment. Nematodes occur wherever "free" water is available[7].
Being the most abundant type of multicellular organism on earth it is no real surprise that they appear in these harsh environments. Nematodes typically feed on plants, microbes and other micro fauna.

In order to survive freezing and desiccation, terrestrial Nematodes can enter a dormant state known as anhydrobiosis(a type of cryptobiosis), only undergoing growth and reproduction when conditions allow it[6, 7].
However these adaptions required to survive limit the biodiversity of the creatures. Only 5 species of Nematode appear on Ross Island and in the Dry valleys, while just a single species is present on a Nunatak in East Antarctica. This is in comparison to "normal" conditions where populations can be millions per square meter with over 200 different species[7].

25 species of Nematode have been collected from other Nunataks however, most of these reside in combination with snow petrel colonies. Only 4 species have been identified to display actively growing populations[7].
Greater numbers of Nematode also occur in samples containing moss or algae then those with less organic matter.

Within the Dry Valleys nematodes occur in around 80% of the favourable soil habitats. This is in comparison to the Tardigrades, other relatively large organisms which occur in less than 20% of these soils[6].

Tardigrades

Tardigrades are tiny cylindrical microorganisms ranging in size from 0.05mm up to a maximum of 1.2mm[8]. They have four pairs of short stubby legs and are one of the few phyla that inhabit almost all climates on earth[8]. Like Nematodes, Tardigrades also occur wherever free water is available[8].

Tardigrades are one of the hardiest organisms on the planet and have even been known to survive the freezing temperatures and intense solar radiation of the vacuum of space[8].
This is due to their ability to undergo cryptobiosis, becoming dormant and ceasing function until conditions are more favourable, enabling them to survive freezing and desiccation as Nematodes do[8]. Obviously this is a favourable attribute to have in the harsh conditions of the Dry Valleys, the most extreme environment they are found in.

The most southerly Tardigrades located are on some Nunataks in Ellsworth Land (75-77°S) including 5 different species. These communities are interesting due to the absence of other typical terrestrial fauna such as nematodes[8].
Because of the lack of competition and predation in the extreme Antarctic environments, population densities of Tardigrades in Antarctica are often between 10 and 1000 times that of more habitable temperate and tropical areas[8]. A surprising fact considering the difficult environment.

Mosses

Mosses along with Lichens are the most visually distinctive things inhabiting continental Antarctica with 18 species inhabiting different zones[9]. Most are green as usually perceived however some xeric (dry inhabiting) species are darker in colour in order to protect against harmful UV radiation. Photosynthesis occurs optimally around 15°C for most species and around freezing point for the more extreme ones[9].

Due to the rapid desiccation that occurs in direct sunlight and the lack of light otherwise, growth is limited with annual shoot increment often less than 3mm[9].
Mosses of the continental Antarctic inland usually colonise rocks and arid soils, however at greater altitudes and latitudes they are chasmolithic, only occurring in cracks[9].

Lichens

The other easily visual organism (or collection of organisms as lichens are) Lichens are distributed across Antarctica and able to inhabit almost any Ice free rock[10]. A symbiotic relationship between algae (which provide the energy) and fungi (which provide the structure and reproduction), they are able to survive a vast amount of habitats.

In some reaches of the southwest Antarctic Peninsula at higher altitudes certain species of Lichen are known to develop stands up to hectares in size. These exist on windswept mountainsides with little snow cover thus exposed to temperatures of down to -50°C.

They are thought to survive these conditions by existing in a region where clouds often develop, thus absorbing moisture directly from the atmosphere.[10]

Inland Lichen oasis occur on Nunataks used as breeding colonies by Snow Petrels, sometimes several hundred kilometres from the coast. The effluent provides nutrients for the Lichen to thrive, often to the point where they provide a distinctive sometimes colourful feature that can be seen from a distance[10].

Six species of chasmoendolithic Lichen have been discovered at altitudes of 1800-2240m. These lichen exist a mere 400km from the south pole at Mount Roland in the La Gorce Mountains[11].
The upper limit for lichen survival appears to be around 2500m[10]. This is in concurrence of winter temperatures down to -70°C and summer temperatures varying from the 20°C of the lichens own microclimate to -40°C[10]. These higher altitude lichens have much darker colouring then the coastal species in order to protect against the more intense UV radiation. In the high inland regions they are barely visible, usually only occurring in micro fissures[10].

Located within the Beacon Sandstone of the Transantarctic Mountains, in what could be regarded as the most severe environment on the planet, are some communities that exist from just below the surface of the rock to depths of 10mm. These are composed of fungal and algal layers which each contribute to the success of the overall organism[10, 12].

Algae and Cyanobacteria

Although two distinctly separate types of organisms (Cyanobacteria are prokaryotic and Algae are eukaryotic), they are largely found in similar habitats and form similar looking mats in large numbers. Both undergo photosynthesis and are primary producers, Cyanobacteria are also often referred to as Blue-Green Algae [4]. It therefore makes sense to class them both as Algae for this purpose.

Terrestrial algae occur in soils and on rocks, usually in the presence of melt water. They also occur inside Lichen and due to a symbiotic relationship with the fungi can exist in areas otherwise uninhabitable for them. Blue-green algae are the dominant types at higher latitudes and in the more extreme environments[4].

Although more common in moist coastal areas, algae can be found visibly in high latitude areas such as the La Gorce Mountains. At 2000m altitude, bright green patches occur between ice and glacial detritus only a few mm thick. Moisture is provided by melt water when the dark detritus is heated by the sun up to 7°C [4, 11].

Under more restricted water supplies, algae only occur in microscopic forms. In the Antarctic dry valleys ice forms polygonal coatings on the soil. Algae can occur in the soil furrows around these ice structures. During the rare summer snowfalls, moisture accumulates in these furrows allowing the algae to grow. Algae is even found in extremely arid soils, although this probably is due to its ability to survive long periods in a desiccated state as it will have little opportunity to grow.[1, 4]

Algae can also be found in range of the geothermal activities of Mount Erebus. This is dominated by a thermophillic (high temperature loving) cyanobacteria as the soil surface temperature exceeds 35°C. Although in the vicinity of an active volcano, this is comparatively tame in terms of extremity compared to the rest of the Antarctic continent. [4]

In the more extreme environments Algae can be found on or within rocks. Epilithic Algae in continental Antarctica can usually only be found in areas where melt water runs over rocks. This is often dominated by blue-green algae as the darker pigments provide better protection from the increased UV rays in the summer and prolongs the cell hydration period when water ceases to be available. [4]

Algae that dwell within or under the rocks occur in zones where water is more restricted such as the dry valleys. Hypolithic algae occur under the edges of semi-transparent stones. These stones protect the soil beneath from becoming too dry whilst still allowing some light to pass through. This environment allows blue-green and green algae to survive in due to the increased moisture retention.[4]

One of the more astonishing facts is that algae can also survive inside the rocks themselves. Either as chasmoendoliths which inhabit tiny cracks in the surface of the rocks. Or as cryptoendoliths which live inside the rocks themselves, inhabiting microscopic gaps between rock crystals. This requires the rocks to be of a certain type, able to either flake and produce cracks, or to have a coarse structure[4]

Light is able to penetrate a few millimetres into the rock and thus providing algae with the means to photosynthesise. The rock can also trap small amounts of moisture, allowing the algae to survive longer without desiccation[4]. Living inside the rock also provides good protection from cold winter external temperatures and high winds. In comparison with this, high amounts of sunshine in summer mean the rocks can heat to above freezing point, and possibly provide protection from UV rays[12].

Conclusion

What are the major limiting factors?

Although these differ from organism to organism the main limiting factors remain fairly consistent.
Moisture, Temperature and Surface Type appear to be the most major limiting factors in Antarctic microbial life along with Light Availability.

Certainly moisture is more than likely the most key component as it is crucial to the development of all life. Although many Antarctic microorganisms can survive states of desiccation, they cannot reproduce or grow in it. Nematodes and Tardigrades enter anhydrobiosis, ceasing functions until water is available again. Algae, lichens and mosses simply cease production of photosynthesis, no longer growing until more moisture becomes available.

All Antarctic micro communities occur in places where moisture can be either freely obtained, or held on to for as long as possible. While the larger organisms only occur in areas of “free” water (Nematodes, Tardigrades), Algaes, Mosses and Lichens have adapted to live in areas of any moisture availability. They either extract moisture directly from the atmosphere, or use up small reservoirs within or under rocks that has been filled with glacial melt water.

Temperature is another crucial factor. This directly links with the availability of liquid water. The more often temperature is above freezing, the more likely the possibility of liquid water due to glacial melt water runoff, hence greater likelihood of life.

Temperature also affects the ability of organisms to photosynthesize, or in the case of Nematodes and Tardigrades, to simply remain active. Photosynthesis only occurs to a few degrees below freezing in the case of the more adapted organisms while its optimal temperature is usually well above 0°C.

Light Availability also plays a vital role, often in the case of influencing temperature but also obviously in the role of photosynthesis. During winter, no light is available so photosynthesis ceases and temperatures drop. In the summer, light is in excess, and can often bring up the surface temperatures to much greater then freezing inducing desiccation and once again ceasing production.

Due to the harsh conditions and small percentage of the year in which life can grow and develop in Antarctica, surface type plays a key role in continental Antarctic life.
Soil stability is a key component of this. An unstable soil gives life little chance to set up a community and thus unstable soils are devoid of life. Stable soils near reoccurring glacial melt water streams provide the most ideal habitats in the dry valleys.

Other important surfaces include rock type. In order for the litho-dependant species to survive only certain rocks are useful. For hypoliths, translucent rocks are needed to let light through. Chasmoendoliths require rocks that flake and crack easily, while Cryptoendoliths require rock with a coarse internal structure.

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