

The terrestrial system in the Ross Dependency, Antarctica

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Living cells, regardless of whether they live as unicells, e.g. protozoa, bacteria, algae, or as part of a multicellular system e.g. fungi, trees, seals, have certain basic requirements in order to perform the process of living and, ultimately of reproducing successfully. With few exceptions these requirements are food, water, shelter and habitat. Habitat can be regarded as a function of the interaction of the food, water and shelter requirements of an organism. The variability of these requirements in the course of time has resulted in millions of species. Environmental and genetic pressures have caused many species to become rather solitary whilst others are quite capable of living and competing in the presence of other species. Some require the presence of other species. Both solitary and communal species live, anthropomorphically, in a remarkable range of places. Bacteria and algae adapted to hot pools, mites which live on the surface of the human eye, mistletoes, and mangroves all testify to this. Regardless of this diversity of habitat all these diverse organisms have a common need to feed and evolutionary mechanisms have resulted in these organisms acquiring the ability to obtain their food in the most efficient way under the prevailing environmental conditions.

Biologists for many years have investigated the fundamental nature of ecosystems and sought to understand the abundance, diversity and interactions of species in a particular habitat. Given the difficulties, technical and intellectual, of such research, nonetheless some overall working principles have emerged which are of world wide application, e.g. pine trees form raw humus layers, Sphagnum only occurs in wet environments, most plants are mycorrhizal. To understand more clearly the functioning of complex ecosystems one can investigate less complex ecosystems. Less complex in the sense that only very few species are involved and that these species occur on simple soils. It is important to stress the need for simple soils. Most soils are complex, heterogeneous mixtures and it is extremely difficult to separate and study the organic, inorganic, living, and dead components. Not only do soils affect plant growth and occurrence but plants may considerably alter the biological, chemical and physical properties of soils by their growth. Within soils there are horizons and within these horizons myriads of habitats for plant roots, animals, and microbes. Interactions occur within and between these microhabitats which may profoundly affect plant growth, e.g. the germination of a spore of a plant pathogenic fungus following passage through the gut of a soil animal and the subsequent infection of a root hair by this fungus.

The simplest soils are those with virtually no humus e.g. the sandy soils on beaches, gravel soils in dried river beds, newly deposited moraines. They are essentially mineral or

inorganic soils and soils of this type can be found in polar and tropical regions.

As one moves from warm to cold climates a marked change in species diversity and biomass occurs. These are concurrent with food, water, shelter and habitat changes to varying degrees. Broadly speaking these are summarised below in an abundance table

	Food	Water	Shelter	Habitat
New Zealand	++++	++++	++++	++++
subantarctic	++++	++++	+++	++++
tip of an antarctic continent 65°S	++	+	+	++++
inner Antarctica	+	+/-	+/-	++++

Food

Although we recognise that most organisms obtain their food ultimately from soil organic matter or humus it should be remembered that organic matter has to be broken down by enzymes to soluble mineral forms before it is in a form suitable for uptake and assimilation by living tissues. Gardeners are well aware of the immediate effects of compost or manure additions on their plants but the effects are due essentially to the large amounts of soluble minerals contained in these additions. These additions are the products of natural decomposition processes and contain in the final analysis only a very small proportion of their nutrients in soluble form. The remaining bound nutrients need to be enzymatically released, a process which to a large extent is dependant on the prevailing soil temperature and the

chemistry of the tissues undergoing decomposition. Hydroponics is testimony to the soluble nutrient idea. Peat deposits in both warm e.g. Florida, and cold e.g. Snares, regions indicate the importance of temperature and substrate quality in decomposition processes.

Water

The bulk of the weight of a living organism, excepting survival structures, is water. In the absence of available water most organisms can survive for only a short time using internal reserves or metabolizing fats. In cold regions there is a tendency for water to occur in the solid phase (ice) for considerable periods of time. During warm periods local topography can markedly affect water availability, e.g. erosion and landslides changing the direction of water flow.

Shelter

Most organisms are extremely intolerant of hot or cold windy conditions. These interact not only to affect organisms physically, e.g. sandblasting, root heaving, marine salt deposition, but markedly lower the moisture content of the air, the soil and plant surfaces and, to a lesser degree, the soil pores. The effects of prolonged exposure on animals of cold, wet windy conditions are only too well known. Plants cannot run for shelter but undergo physical and chemical adaptations to withstand such conditions.

Habitat

Given the often terminological inexactitudes of such things, it is quite common to refer to the places where organisms occur in holistic terms, e.g. plant environments, forest ecosystems, grassland ecosystems. Often these terms are used in a more specific but still holistic sense, e.g. the Sphagnum habitat, niche or environment. However one can, on closer study, ultimately reduce all these terms to the surface level and consider large surfaces, e.g. the Canterbury Plains, and small surfaces, e.g. sand particles. Arguably perhaps, any surface provides a habitat for a suitable organism. It is at surfaces that biological systems can begin to be understood according to the laws of chemistry and physics in a most fundamental fashion.

Plants for example interact with their environments at their surfaces, e.g. nutrient absorption occurs at root surfaces. These surfaces are colonized by bacteria and fungi which obtain food from root exudates. In turn these microbes are grazed by protozoans and mites. Adjacent to all these organisms are the surfaces of the organic and inorganic phases of the soil. At the grosser surface levels these systems also occur, e.g. opossums grazing leaves of forest trees on stony soils. Animal gut cells and leaf cells provide surfaces for nutrient fluxes and microbial attachment where the gross macro climate effects are not felt.

A rock has a smaller surface area compared to a rock which in the long process of weathering has become converted to smaller particles e.g. sand and clay sized particles. Accompanying these size reductions are the physical, chemical, and often biological release of nutrients from inorganic crystals which markedly

affect the local pH and salt concentration on these surfaces and in the pores formed between surfaces. Molecular films of water will occur on these surfaces which, although readily available to surface microbes, will be largely unavailable to plant roots which can only readily extract capillary and free water. The availability and occurrence of food, water, and shelter are greater and more accessible on surfaces to microbes ('nanoclimates") than will be the case with organisms of increasing size e.g. mosses and trees, as exemplified by micro and macroclimate plant studies. Surfaces are universal in nature but the types of organisms colonizing them differ at the nano, micro, and macro level depending on the size of the organisms and the amounts of food, water, and shelter which they require.

If one turns now to the Ross Dependency with the above points in mind one can examine in more detail the diversity and abundance of organisms. In the case of large animals and plants one can understand their absence on the grounds of insufficient food, water, and shelter from the macro to the nano level. Antarctica is characterised by cold, dry conditions and mineral soils. Animals select food because of palatability and nutritive value. Higher plants are rich in nutrients. Lower plants such as mosses and liverworts are poor in nutrients and any antarctic animals would have to consume considerably more of these plants in order to extract sufficient nutrients for maintenance of body weight, let alone increase and reproduce. Reindeer and caribou numbers in the Arctic are limited by food abundance and these animals have to forage over a considerable area for sufficient

food. The carrying capacity of Antarctica for these animals is nil. However sufficient lower plant and microbial biomass occurs to support quite large populations of tiny mites and collembola. These animals are limited in their distributions by water availability.

Apart from algae; mosses, liverworts, and lichens are the plants which occur in the Ross Dependency and the species and abundance of these is determined by water and shelter availability. These plants in general, because of their slow growth, only require very small amounts of nutrients in order to allow for the tiny growth increments over the very short growing season, if any, each year. With the exception of carbon, and regarding nitrogen as a special case, nutrients such as phosphorus and calcium need to be absorbed by plants from their surroundings. The amounts required are very small; indeed laboratory culture of mosses and liverworts involves the use of dilute salts solutions, the concentration of which approximates that in rain or snow. Since rainfall does not occur in the Ross Dependency, snow and ice melt provides water and this water will contain low concentrations of available nutrients. During the brief antarctic summers melting will create surface films and even local seepages which in the dry air will evaporate but not before causing a flush of activity in the local communities which, in the case of microbes at the 'nano' level, may be sufficient to allow for population size increases which in turn may increase the grazing activities of soil animals on these microbial lawns. Such transient melts are probably of limited effect on plant dominated communities, but if topography is such

that large wind blown snow bank, ice deposits, or glacier snouts occur, then summer melting will allow for the formation of small streams and drainage channels which may persist for approximately ten weeks (from late November to late January) provided the water flow rates are not high. Lower plants establish well along the borders of these streams and are bathed in dilute nutrient solutions. These nutrients will be enhanced by natural release from rocks and small inorganic particles during weathering processes produced as a result of freeze/thaw, wet/dry cycles. Due to the porous nature of the coarse textured soils, there will be a limited amount of lateral water and therefore nutrient seepage into the sides of these streams, extending for only a few metres but nonetheless available for plant colonization.

Leaching, the downward movement of water and nutrients into the soil, does not occur in antarctic soils due to a) lack of rain, and b) the ablation and evaporation of snow melt under the prevailing dry conditions. Rather one finds upward movement of limited water and nutrients from the permafrost layer which melts slightly due to soil heating during summer. Surface soil temperatures are approximately 10°C higher than current air temperatures (chest height - 8°C). This water evaporates at the soil surface depositing salts which can form thick crusts toxic to plants and microbes. At soil temperatures which approximate 10°C the enzymatic decomposition of dead plant, animal and microbial tissue is quite slow and very few nutrients in available form are released from these sources. Dead moss plants buried for five years in antarctic soils have lost only 4 percent

of their original dry weight over this time. It would seem that the scavenging abilities of plants at the micro level and of microbes at the nano level are very great indeed.

In the case of the element nitrogen an interesting situation exists. This element is a constituent of proteins, chlorophyll and nucleic acids and is regarded as the most limiting element in nature. Many organisms have the ability to fix nitrogen; that is they can convert nitrogen gas into organic nitrogen compounds. Such organisms are independent of saprophytically derived mineral nitrogen. Although advantageous such a process is energy demanding and reduced in the presence of mineral nitrogen. Given the short growing season and nitrogen rich waters there is insufficient evidence to suggest that nitrogen fixation is important in Antarctica although many microbes certainly have the potential to fix nitrogen. It is more likely that plants and microbes satisfy their nitrogen requirements from melt waters.

Lower plants form thin layers or cushions in the shelter afforded by rocks, glaciers, small valleys, and depressions from the prevailing southerlies on Ross Island and the coastal regions of Victoria Land. Westerly winds from the polar plateau blow through the dry valleys orientated west to east along the Victoria Land coast. These strong dry winds restrict plant establishment to the lee sides of rocks, stones, and glaciers. Southerly winds blowing on to coastal regions deposit sea salt. Often these deposits can be seen on the soil surface up to a kilometre inland where local topography has helped to channel these salt laden winds. These deposits, additional to those derived from permafrost, will limit plant distributions.

The stability of soils, particularly on slopes, is rather marginal due to the lack of binding humus and clay minerals. Often rather large water flows can occur causing erosion and landslides, which divert water to new soil areas which may in time become colonized. The fate of stranded plant communities is rather uncertain but they can survive in the freeze dried state for up to six years.

Sunlight and shading are related to habitat at the macro and micro level and antarctic organisms have to cope for up to six or seven months with little or no light. On limited observation plants can survive these conditions, as evidenced by the flush of new growth in the summer season. Perhaps a combination of freeze drying, antifreeze substances, and limited heterotrophy are the strategies which these plants employ. It should be noted that plant growth is very slow and although a flush of green shoots often occurs the actual growth increments are too small to be satisfactorily measured, likewise the lateral spread. The rates of colonization of mosses are so imperceptible that the opinion exists that present day communities of mosses are many centuries old. This point is strengthened by the fact that, five years after removing moss plants from a metre square area in a moist, sheltered moss community, no moss plants have regenerated despite this site being surrounded by healthy moss plants. Furthermore, the number and spread of moss shoots in an area adjacent to the cleared site, but covered by a perspex box for 2 years, have dramatically increased. It is likely that the lack of wind, increased humidity and temperature in the covered area are

factors enhancing plant growth. So far I have placed the emphasis on plants such as mosses, but it is pertinent to consider, in more detail, what are often termed lower organisms, such as blue green algae, bacteria and lichens. The green algae are classified as plants but I will include them under the umbrella term of microbes for convenience.

Lichens, combinations of different types of microbes, are the hardiest plants known. In Antarctica they can withstand the extremes of food, water, shelter and habitat better than mosses and liverworts. They are, though, very sensitive to salts and do not occur on unstable soils, particularly in exposed coastal regions. They commonly occur on rocks on mountain sides which often have a cloud layer from which they absorb moisture. Most are pigmented and this seems to help them overcome the high ultra violet light levels and also to absorb solar radiation.

It is a not uncommon experience to visit antarctic regions where at first sight plants do not appear to occur - the visible surface habitats are bare. However these observations must be treated cautiously for several reasons. A great many microbial communities require the use of high powered microscopes for study and identification. Many 'bare' soil surfaces, cracks in rocks and moss surfaces prove to contain thousands of microbial cells when samples are examined under high magnification. We need to turn from a macro, through micro to a nano view of things at this level. Microclimates of plants have long been recognised as differing from the macroclimate at, say, chest height. At the microbe level "nano climates" occur where the laws of physics and chemistry prevail in a most fundamental fashion to render the

microbial environment a most hospitable one in terms of food, water, shelter and habitat.

There is a group of microbes which live within porous sandstone rocks below the rock surface - the endolith communities of bacteria, fungi, algae and lichens. For example, on the edge of the polar plateau at about 2000 metres in rocks devoid of snow, one can see the green, yellow or black discolouration of the underlying organisms. Here they are completely protected against the strong cold dry winds and due to the porous nature of the rock one finds that the organisms themselves act as water sponges. I have found that the macroclimate RH (relative humidity) in this area is 8 per cent, the microclimate RH 25 per cent and the RH inside the rocks is not less than 93 per cent.

Many streams do not contain mosses on their margins and this can be due to flow rates and soil instability. However, abundant algae, unicells or filaments, can be found on the sheltered surfaces of rocks and stones in these streams. Filamentous algae are more common in slower flowing streams where they are unlikely to be blasted by water borne inorganic particles. Algae will be bathed in dilute nutrient solutions and at a reasonably constant temperature above that of the air during the summer melt season. One can observe the metabolic activity and growth of some groups of microbes, e.g. the blue green algae and diatoms. The bubbles of oxygen rising to the surface from algal growths and the coloured transient diatom blooms in still shallow pools testify to this activity. It is the algae, particularly the blue greens, which probably constitute the largest biomass and provide the

most extensive visible plant cover in Antarctica. Water is the most limiting factor affecting their distribution.

Even glaciers are not devoid of life. Pools, formed as a result of dark rocks melting through the ice, harbour distinct microbial communities which have enough food and shelter to sustain them over the short summer.

There are two apparently paradoxical habitats in Antarctica which are extreme in the sense that they either contain abundant humus or organic matter which is chemically quite different from that in garden or arable soils, or are heated. Both support rather specialized organisms.

The ornithogenic or guano soils which accumulate under nesting penguins contain very large amounts of nutrients in concentrations which are inhibitory to most organisms. This organic matter derived from penguin excreta is prevented from rapid decomposition by the relative absence of water, although laboratory experiments have indicated that, at 4°C in the presence of water, decomposition is far more rapid than could occur in, for example, temperate forest humus. Special algae do live in guano pools and the enriched meltwater streams which flow through the colonies. In these instances there is no shortage of food, water and shelter. Elsewhere, on the drier areas of penguin rookeries, one finds only bacteria and fungi living in the surface crusts. Their activity is only limited by water availability.

The volcanic regions in the Ross Dependency are exemplified by Mts Erebus and Melbourne. Soil temperatures near the summits about 3000 m are in the vicinity of +40°C. These steam heated

soils contain abundant organisms and unlike other Antarctic soils are rather acid and permanently moist. The Melbourne soils harbour rich growths of a moss (Campylopus) which as far as is known occurs nowhere else on the continent. The Erebus soils harbour a protonemal moss which has not been observed to form leafy tissue. Both sets of soils harbour a diverse algal community, with thermophilic algae and microbes common on Erebus soils due to its higher temperature. The occurrence of Campylopus on Melbourne may be important from a biogeographical viewpoint since the genus also occurs on Deception Island. It is likely that wind is the dispersal mechanism and in a wider sense this mechanism, along with water flow, are the two most important dispersal systems in Antarctica.

Only a limited amount of botanical mapping work has been done in the Ross Dependency, but from such work one can predict from the detailed topographical maps available and on the basis of the four factors discussed above where plants would likely occur. From an appreciation of 'nano climates' we would expect a wider distribution of microbes. Furthermore, as one moves north along the coastal regions, one would expect slightly milder climates, e.g. warmer temperatures and moisture bearing winds, and hence a greater abundance and diversity of organisms. From the limited data available this appears to be the case.

We have become accustomed, via the popular press, to the lack of plants and terrestrial animals in Antarctica and have regarded Antarctica as a cold, dry, extreme environment and often refer to the fragility of the place. Close inspection reveals

that a limited number of terrestrial plants, animals, and microbes obtain enough food, water, and shelter to colonize successfully diverse habitats. Water and shelter are the main factors limiting distribution. Higher plants and the animals which feed on these plants are unable to obtain sufficient food, water, and shelter in Antarctica and find these conditions on the subantarctic islands, the tip of South America, and the mountainous regions of New Zealand.

The Antarctic environment is not intrinsically fragile as is shown by the fact that plants and microbes occur widely and will be observed provided one looks a little more searchingly in the appropriate habitat than would normally be the case on typical plant forays in New Zealand. Even in New Zealand there are precedents for close observation of the soil surface, e.g. lichen and fungal forays. Regrettably the fragility of the Antarctica environment originates entirely from human activities.

I have concentrated in this article on the factors and processes which affect the occurrence of a wide variety of organisms in the Ross Dependency and have refrained, perhaps surprisingly to many, from detailing the species of organisms involved. This is due to several reasons:- a) there are many hundred of bacterial, fungal and algal species compared to the combined score or so of mosses, liverworts and lichens, b) there appear to be great difficulties still unresolved as to the precise identification and taxonomy of many of these plant species. For example the mosses do not form sex organs and some may show considerable morphological variation, e.g. Bryum antarcticum, B. elegans and B. argenteum. It should be a cause

for concern that lower plants generally still do not receive the attention they ought.

On reflection, at the microbial level, Antarctic ecosystems are probably as complex as their temperate counterparts although at the plant level they are simple. The fundamental action of many important ecological factors, e.g. water, temperature, which are often confusingly interactive in complex ecosystems, can be more easily delineated and studied in these simple plant systems. The results from such studies may lead to a more understandable set of ecological principles, which would be of assistance in unravelling complex ecosystems.

The authors of the two articles on Antarctica are both members of the Society. Laurie Greenfield is well known to members, having talked to us, as well as for his work in Antarctica.

Paul Broady submitted his article while still lecturing in the Botany School, University of Melbourne. Since then he has been appointed to the position previously held by Graeme MacRaid in the Department of Plant and Microbial Sciences (Botany Department), University of ~~Canterbury~~.

The above two authors and David Given have recently contributed to a scientific report on the Antarctic and it is hoped that one, or some combination of these three, will provide us with an article giving a fuller cover of the antarctic biota for the next Journal.

The map of Antarctica, on pages 38-39, was drawn by Paul Broady, the inset was added with the assistance of the Antarctic Division D.S.I.R. and the University of Canterbury, Printers.