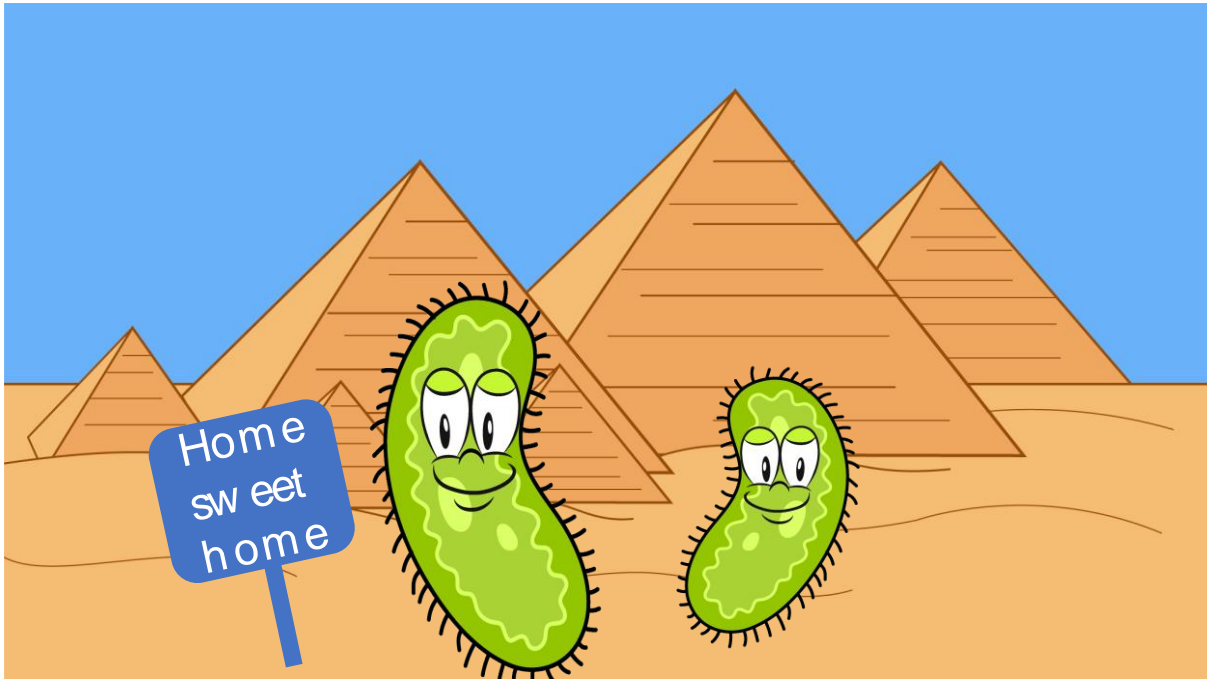


## Microbes in Deserts – The Ultimate Survivors

*Class ice-breaker question:  
Can you name something that lives in a desert?*

*It is more than likely that camel, cactus, or lizard are among the most popular picks – but did you know that the most important living component of deserts are microbes?*



(Image credit: Stephen Pointing)

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# A child-centric microbiology education framework

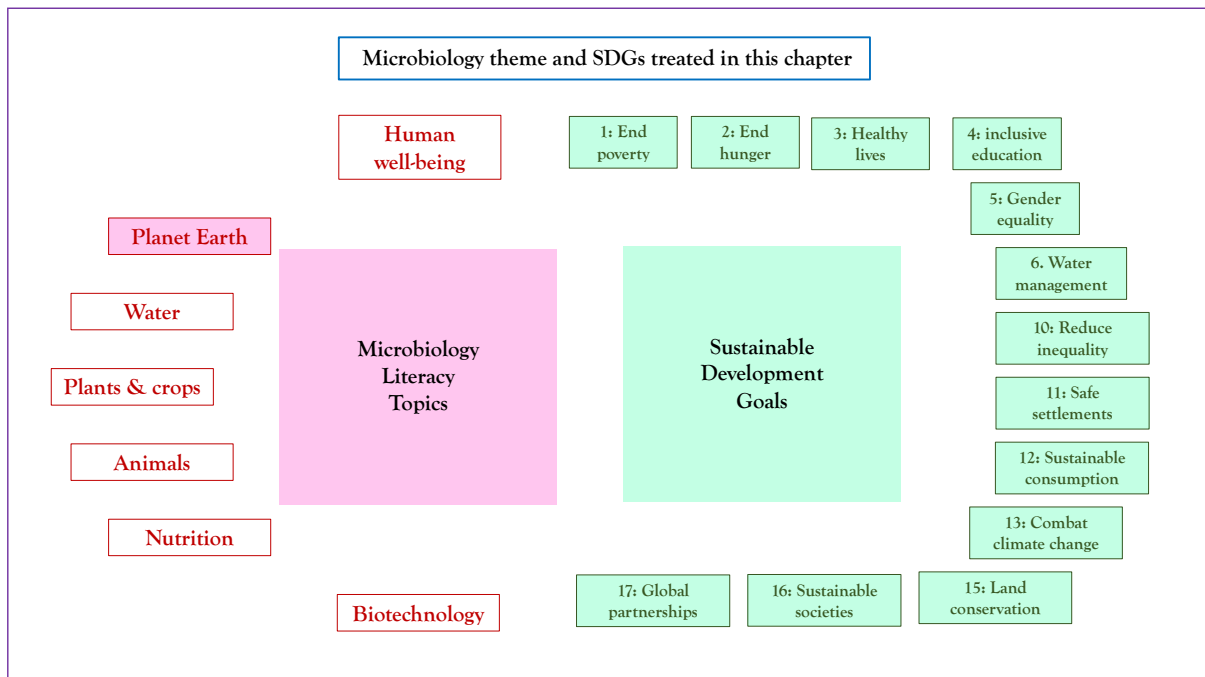
## The Ultimate Survivors - Microbes in Deserts

### Storyline

Most of the world's population do not come into contact with deserts but *they occupy over one third of all land on Earth*. The lack of liquid water – which is the essential ingredient for all life – creates *severe limits for the biodiversity encountered in deserts*. Most people will identify camels, cacti and lizards as life adapted to deserts but *the most successful and important desert-dwellers are in fact microbes* that grow as a crust over the desert surface. They stabilize the sandy soil and help prevent dust storms, and provide a habitat and nutrition for other desert creatures. They are also important in conditioning soil for agriculture in desert soils and so their *disturbance can have harmful effects on natural and human systems*. Desert microbes are also thought to be the *closest analogue for potential life on the dry surface of Mars*.

### The microbiology and societal context

This topic links to sustainable development goals of land conservation, ending hunger and combating climate change. The microbiology content links to relationships with the planet Earth, water, animals, plants and crops.



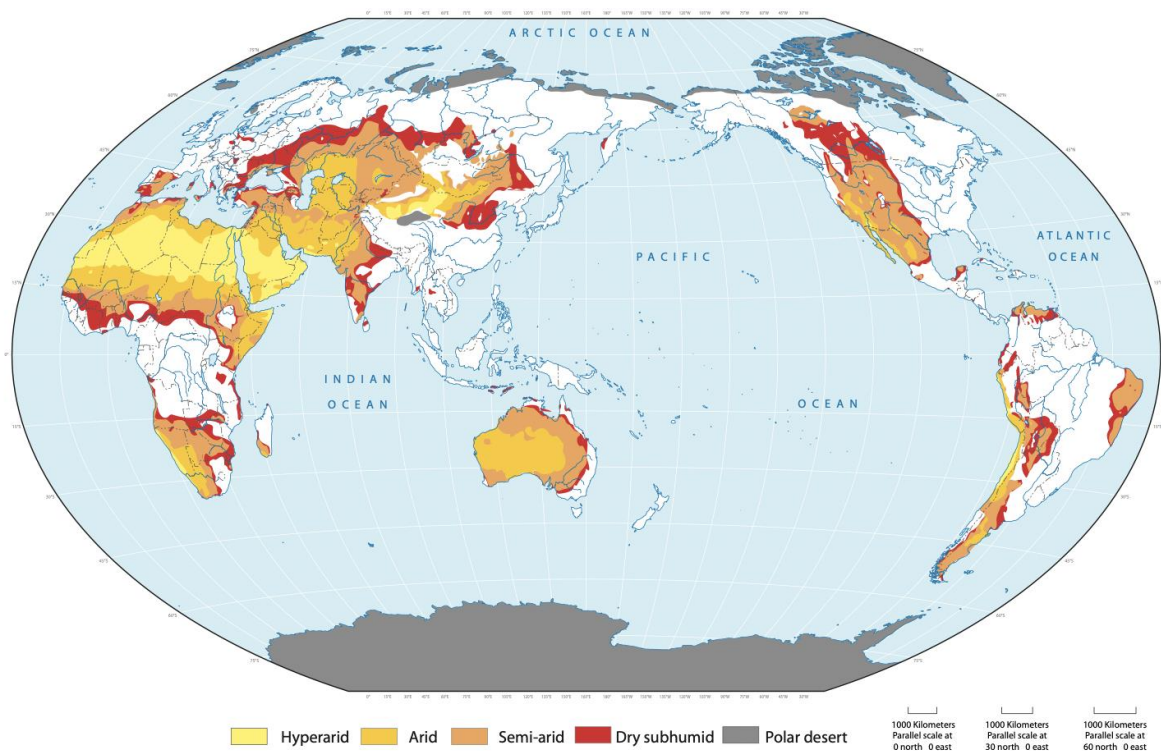
### The Ultimate Survivors - Microbes in Deserts

1. *How do we define a desert?* A desert is an ecosystem that experiences sustained moisture deficit, which means inputs from precipitation (i.e. rain, snow, fog) are very low and water loss from evaporation (including evapotranspiration, the water that evaporates from plants) is high. The United Nations Environment Programme (UNEP) defines a desert by its aridity, which is measured by the ratio of precipitation to potential evapotranspiration (P:PET). There are four categories of desert that are generally recognized and they are characterized by the P:PET:

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Dry subhumid	0.51-0.65
Semi-arid	0.21-0.5
Arid	0.06-0.2
Hyper-arid	$\leq 0.05$

Deserts are the most abundant terrestrial ecosystem and they occupy just over one third of all available land on Earth. Take a look at how deserts can occur in both hot and cold places – the Arctic and Antarctic are large deserts because the water is frozen and so is not available for living organisms.



(Image credit: Stephen Pointing)

2. ***What is it like to live in a desert?*** The greatest stress for life in deserts is the lack of moisture because all life has a requirement for liquid water in order to survive. This is because the structure and function of cells (the building blocks of all life) depend upon liquid water.

Some animals and plants have adapted to deserts by finding ways to conserve water in their bodies, e.g. lizards excrete uric acid crystals instead of liquid urine, cacti have waxy coatings on their leaves to reduce evapotranspiration. However, they still need to access liquid water periodically to survive. So what happens in hyper-arid deserts where water is almost never available? The answer is that microbes are the only life that can thrive, they are the ultimate survivors in deserts. This is because they are able to completely shut down their cells and lie dormant when water is scarce, and then reactivate quickly and take advantage of brief periods when water becomes available. Organisms that display this ability are termed poikilohydric.

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3. *What type of microbes thrive in deserts?* The most important microbes in deserts are actually very diverse communities of different microbes called biological soil crusts. They are literally “invisible” to the naked eye because they are often mistaken as being part of the soil. They include many species of bacteria, fungi, algae and lichens. The most important component are cyanoacteria – and these are photosynthetic bacteria that act as the main primary producers in deserts. They are also extremely important because they help to provide cohesion to the desert surface and prevent soil particles from being blown away, they regulate water movement between soil and air, and help to provide nutrients that can support desert plants and animals.



(Image credit: Stephen Pointing)

On exposed rocks, dense lichens (and simple plants called mosses) can develop and these are important in the weathering of rock to create new soil particles because they break down the rock surface as they grow (by secreting acids that dissolve the rock matrix).



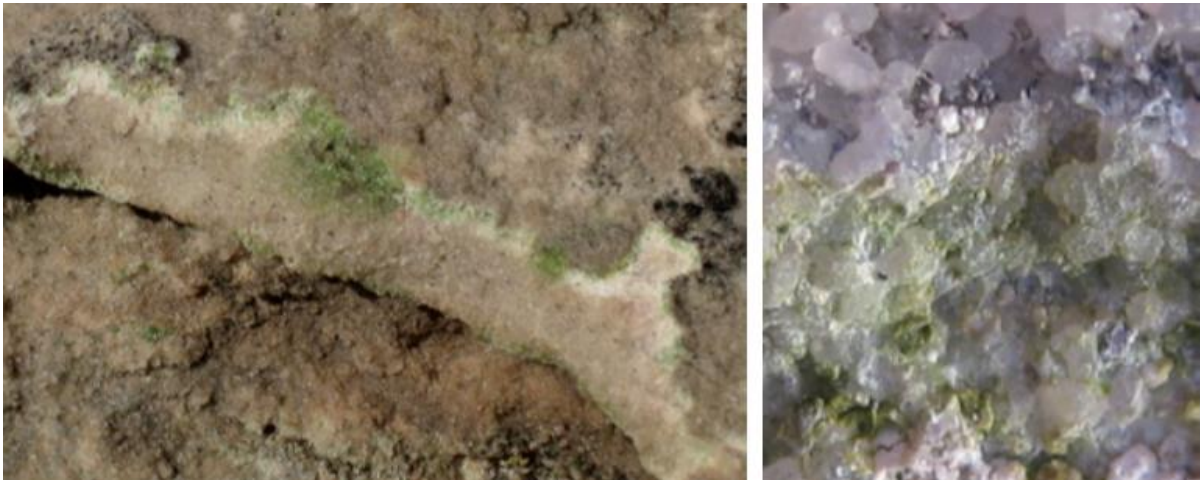
(Image credit: Stephen Pointing)

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As the moisture stress in deserts becomes more extreme, even the biological soil crusts find it harder to survive. In the driest hyper-arid deserts, microbial life is the only abundant life form and it is restricted to “refuges” where they can avoid environmental stress. Life in these refuges is very patchy and marks the dry limit of life on Earth.

This generally involves retreating beneath or within rocks where water condenses more frequently than in exposed areas. Microbes beneath rocks are called hypoliths whilst those within rocks are called endoliths. The rock also helps to protect the microbial cells from other stressful factors in deserts such as UV radiation.

In most cases they are dominated by cyanobacteria because photosynthesis is the only way to obtain energy in a habitat where other food is very scarce. Some microbes have even evolved ways to obtain energy from things that we would not regard as foods such as hydrogen gas in the atmosphere, and this may be useful when there is no other food available.



The left panel shows a rock surface that has been broken off to reveal a layer of green cyanobacteria growing just below the surface. The right panel shows a close-up of the cells growing among the rock crystals. (Image credit: Stephen pointing)

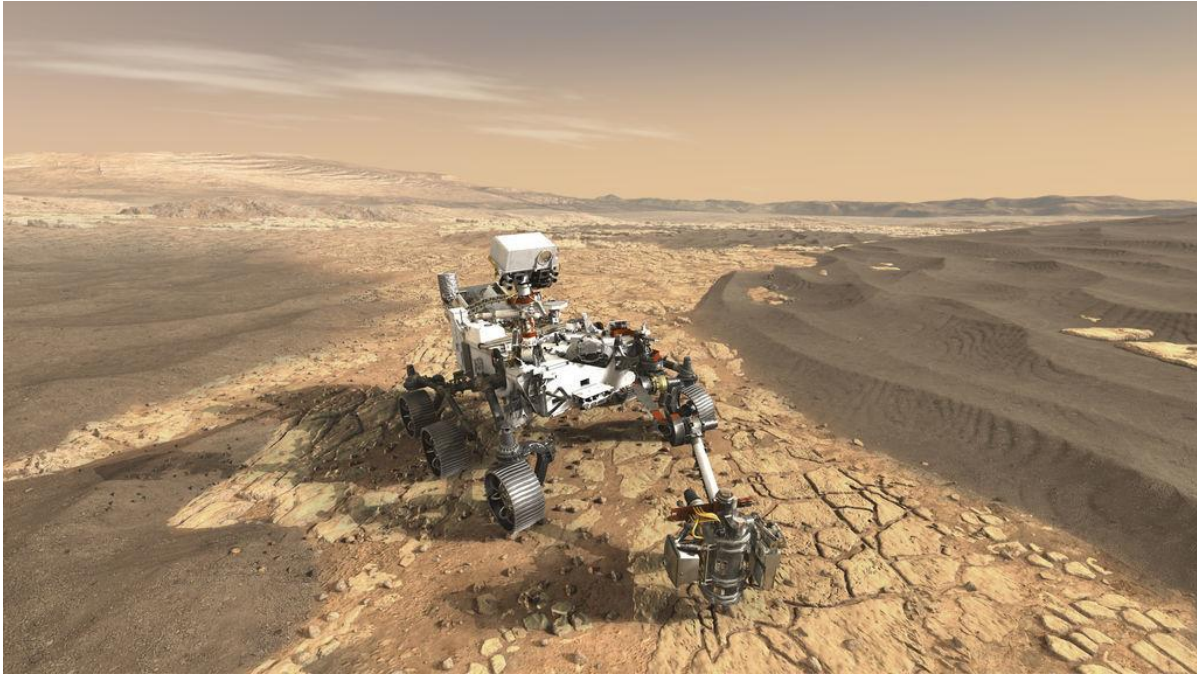
4. ***Why are desert microbes important to humans?*** Over 5 billion hectares of desert land is currently used by humans for agriculture (about 5 times the size of the USA). The UNEP has estimated that approximately two thirds of this land is degraded or is undergoing desertification (becoming more arid). Part of this is due to human land use, but climate change is also a factor. Any reduction in agricultural productivity will affect these regions and the harmful impact will fall disproportionately on poorer communities.

There are other pressures due to changing land use, including recreation that degrade the biological soil crusts and reduce stability of desert soils. This causes dust storms that can impact human infrastructure, health and safety. It can also impact natural ecosystems, e.g. desert dust deposited in the oceans can affect plankton and coral communities.

5. **Why desert microbes may be “out of this world”.** Did you know that deserts are not only found on Earth? The surface of Mars is a vast desert that is much more arid than any desert on our planet. However, there may be small pockets where liquid water occurs on Mars and in the past the planet was much wetter. This has led a branch of science called astrobiology to investigate the possibility that life adapted to desert conditions might just have arisen on Mars – and thus desert microbes are the closest analogue for Martian microbial life. The US space agency NASA has invested considerable effort to map the past and present occurrence of water on Mars,

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and the current mission with a lander called Perseverance began searching for traces of microbial life within the surface rocks and sediments in early 2021.



Artist impression of Perseverance searching for life on Mars surface. The arm extended in the foreground has a drill that will recover samples to look for traces of life below the surface. (Image Credit: NASA)

### Relevance to Sustainable Development Goals and Grand Challenges

- **Goal 1. End poverty in all its forms everywhere.** Promoting sustainable practices in dryland agriculture and ecotourism can help alleviate poverty. Central to this is an appreciation of how microbes are important to stabilise and protect surface soils
- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.** Dryland agriculture is challenging but it can help in providing food security to local populations and managing the microbial biological soil crusts can assist with sustainability by preventing erosion and helping with soil fertility.
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages.** Desert dust storms that arise due to loss of microbial biological soil crust can cause respiratory distress and disease, thus highlighting the need for their conservation and management.
- **Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.** Promoting inter-generational understanding and respect for the natural balance of dryland ecosystems is critical for long-term management.
- **Goal 5. Achieve gender equality and empower all women and girls.** Food production and cooking roles often fall disproportionately on females and children, and so improved desert soil health and associated yield improvement can contribute to improved gender equity.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all.** Water is scarce in drylands and for soils the biological soil crust helps retain water that can then sustain agriculture and promote crust growth that will reduce soil erosion.

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- **Goal 10. Reduce inequality within and among countries.** Many poorer countries have significant populations that live in and rely upon drylands and so improved management with understanding of the important role of microbial soil crusts is important.
- **Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.** Static and nomadic settlements in drylands benefit from the improved soil stability provided by microbial biological soil crusts. The problem of desert dust is also a transboundary issue and can affect distant cities, e.g. Beijing is impacted by dust from the Gobi Desert.
- **Goal 12. Ensure sustainable consumption and production patterns.** Marginally productive land such as drylands require careful management that fully considers the role of microbes in cohesion and nutrient cycling in soils.
- **Goal 13. Take urgent action to combat climate change and its impacts.** Desertification is increasing as a consequence of climate change and so the scale of the challenges outlined here are all likely to be exacerbated in coming years. Action to devise strategies that improve stability and productivity in dryland soils using microbes are required.
- **Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.** Desertification and land degradation due to climate change and other human impacts, e.g. recreational use, can be mitigated through careful management of microbial biological soil crusts.
- **Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.** Food security and minimising natural disasters such as dust storms can contribute to greater stability and satisfaction among societies living with the impact of drylands.
- **Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development.** The impacts of desert dust are a transboundary issue and require international cooperation to be addressed. The rise in human populations living in drylands in developing and developed countries is increasing due to population growth and climate change and the magnitude of the problem makes meaningful action beyond the capability of any one country alone.

### Potential Implications for Decisions

#### 1. *Individual*

a. Direct subsistence: Can I produce sufficient food to feed my family in our dryland home? Will we have to relocate to another area and how will this affect my family's wellbeing?

b. Direct recreational: Are my leisure activities contributing to degradation of microbial soil crusts and destabilization of dryland soils? Can my cycling, off-road vehicle, and other activities in deserts be enjoyed elsewhere with less impact?

c. Am I linking my activities in deserts to the transboundary problems caused by desert dust storms? Should I feel responsible for this?

#### 2. *Community policies*

a. Local environmental consequences: Is it appropriate to restrict access to drylands? How should subsistence, recreational and cultural usage be evaluated and prioritised?

b. Public health: How does the degradation of dryland soils and desertification affect burden on local healthcare?

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c. Education: Can local populations in drylands be better engaged and encouraged to care more for their surroundings?

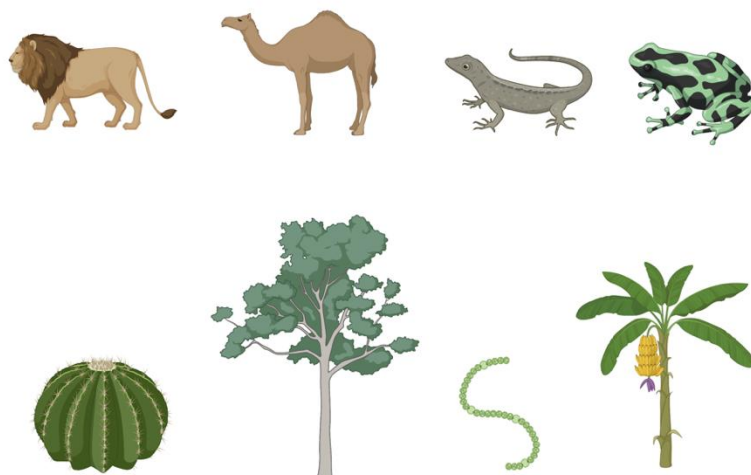
### 3. *National/international policies*

- a. Provision of relief and alternative homes for populations affected by desert degradation and desertification.
- b. Targeted healthcare provision for desert-related problems, e.g. respiratory illness due to desert dust.
- c. Developing a greater awareness of social justice to encourage a culture of care at the national level.
- d. Can national strategies alone be sufficient to prevent the negative impacts of desertification and desert dust storms? Develop a transboundary international approach that engages across borders.

## Pupil Participation

### *Exercises*

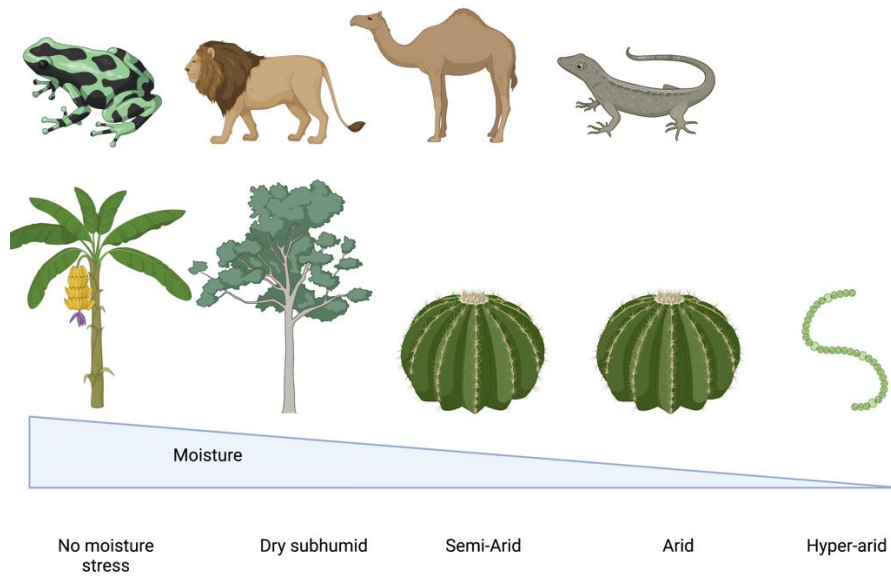
1. **How do we define a desert?** What do the values used to describe a desert mean to you? A desert receives less than 250mm precipitation in a whole year, how does that compare to where you live? (encourage students to search for data online).  
*Examples:* On average, a tropical country such as Singapore receives 2,200mm precipitation per year, and a temperate country such as the UK 885mm (opportunity to draw a simple graph to display values).
2. **What is it like to live in a desert?** Ask students to sort these icons into order based on how they might be able to cope with moisture stress (the green chain of cells are microbes!):



(Image credit: Stephen Pointing)

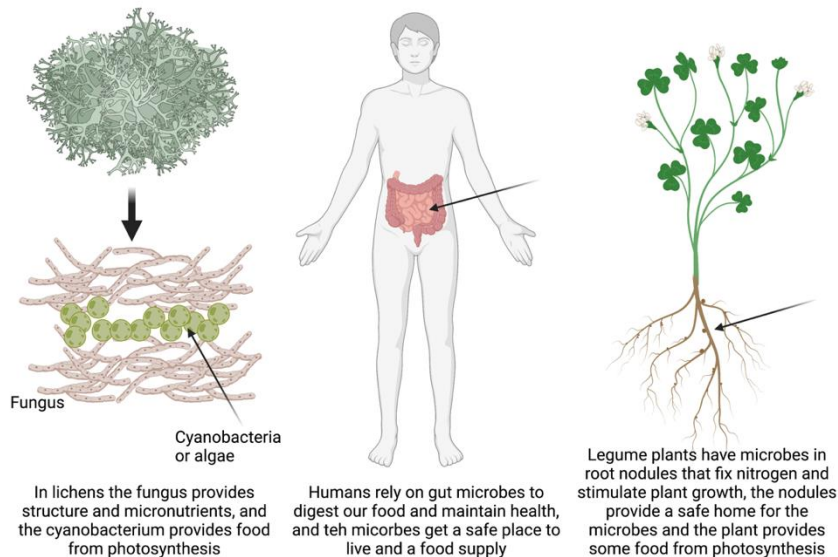
The different ability of organisms to cope with moisture stress creates a gradient of biodiversity in deserts. Here the teacher can highlight the gradient shown by the sorted icons and add the names for the different desert types.

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(Image credit: Stephen Pointing)

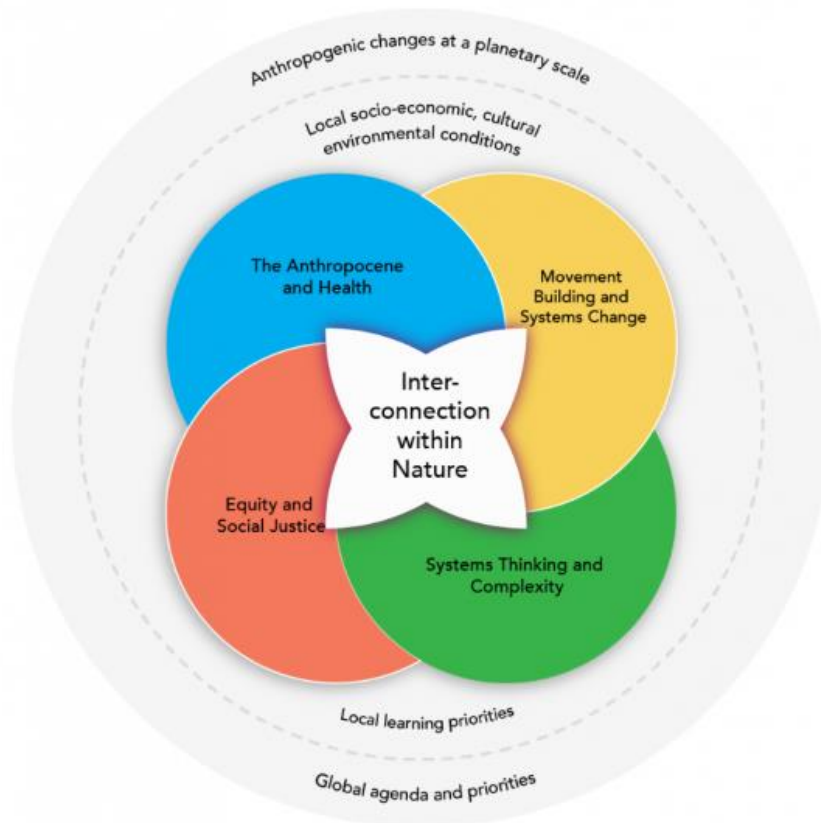
- What type of microbes thrive in deserts?** Lichens are a *symbiosis* between a fungus and a cyanobacterium or alga and this is a common strategy for many forms of life. In lichens the fungus provides a physical structure and attachment to the rock (i.e. a safe home) and provides micronutrients from dissolved rock (e.g. iron) to the cyanobacteria, and they in turn donate to the fungus some of the sugars they are able to make via photosynthesis. Symbioses are common in nature – the teacher can highlight other important symbioses here too, e.g. cattle and rumen microbes; soybeans and root nodule nitrogen fixing bacteria; termites and their fungal gardens – and of course humans and our own gut microbiome.



(Image credit: Stephen Pointing)

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4. **Why are desert microbes important to humans?** The wider connections of desert microbes with the health of humans and the environment is part of a concept called *planetary health* that seeks to understand the linkages between human disruption to the Earth's natural systems and human health and all life on earth. Using the diagram below the teacher can invite students to make connections between the environmental and human factors where desert microbes may have an impact.



(Image credit: Planetary Health Alliance)

### *Additional activity suggestions (longer duration activities)*

#### 1. Design a poster to educate people of the need to protect desert microbes

Learning goal: To emphasize that human and environmental futures are closely entwined.

Teacher briefing: Ask students to consider how to promote to a recreational audience at the entrance to a national park, the following: i) recognition of biological soil crusts, ii) highlighting their ecological role, iii) the consequences of disturbance, and iv) advice for minimizing impact. The highly effective “Don’t Bust the Crust” strategy by the US National Parks Service is a great example:

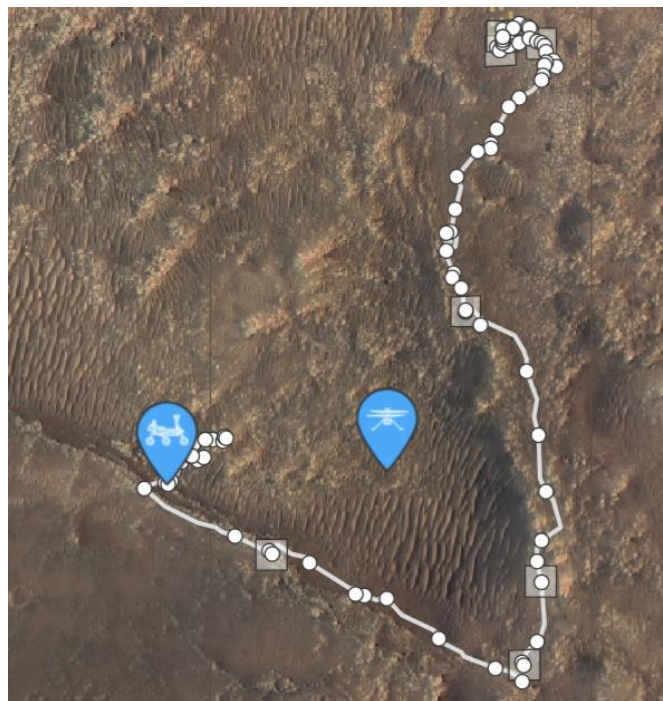


(Image credit: US National Parks Service)

**Activity 2: Design a mission to search for microbes in the deserts of Mars**

Learning goal: To reinforce the concept that microbes in the most extreme deserts are found only in refuges below or within rocks

Teacher briefing: Ask students to design a rover with three specific questions: 1) What part of the Martian desert would your rover look for samples? (beneath the surface in rocks or sediments, near to evidence of past water or present water ice), 2) What would your equipment try to detect (try to steer students towards ideas to detect photosynthetic cyanobacteria, such as pigments) The NASA Perseverance website has plenty of detail about mission design including 3D interactive graphics and videos. [Note: it is highly unlikely that extant microbial life exists on Mars].



(Left icon: Perseverance rover location on Mars in December 2021, right icon: Landin site February 2021. Image credit: NASA)

## A child-centric microbiology education framework

### The Evidence Base, Further Reading and Teaching Aids

1. UNEP booklet on global deserts and their importance to humanity: <https://www.unep.org/resources/report/our-planet-deserts-and-drylands>
2. A scientific article by desert microbiologists Stephen Pointing and Jayne Belnap about the diversity and role of microbes in deserts: Nature Reviews Microbiology volume 10, pages 551-562 <https://www.nature.com/articles/nrmicro2831>
3. Planetary Health Alliance website that describes how human health and that of our environment are linked: <https://www.planetaryhealthalliance.org/planetary-health>
4. A short animated video (7 mins) by the author on how desert microbes are helping scientists in the search for traces of life on Mars: <https://www.youtube.com/watch?v=1osuvGZGQHo>
5. NASA Perseverance website: <https://mars.nasa.gov/mars2020/>

### Glossary

*Astrobiology*: The study of life in the universe including the origin, potential distribution on other planets and future trajectories for life.

*Cyanobacteria*: A phylum of bacteria that are capable of oxygenic photosynthesis, analogous to that which is carried out by green plants.

*Desert*: a region experiencing prolonged moisture deficit, characterized by reduced and specialized biodiversity relative to moisture-sufficient regions.

*Lichen*: A symbiotic relationship between a fungus and a green alga or cyanobacterium.

*Planetary health*: The study of human health and wellbeing and the interrelationship with the natural systems on which it depends.

*Poikilohydric*: The ability to survive lack of water in a desiccated form and rapidly resume biological activity when water becomes available.

*Symbiosis*: A close and sustained interaction between two different organisms.