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BIODIVERSITY
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BLOWING IN THE WIND: MICROBIAL TRANSPORT IN THE ATMOSPHERE

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YOUNG REVIEWERS:

HARMONY
AGE: 12

SHRIYA
AGE: 13

Airborne microbes are microorganisms that are suspended in the air. Airborne microbes include bacteria, viruses, fungi, and other microorganisms. Some airborne microbes can cause infectious diseases or other health problems, while others may not be harmful. Therefore, the role of airborne microbes in shaping atmospheric, ocean, and land-based ecosystems is extremely important. Scientists found that airborne microbes can be transported by wind/air for thousands of kilometers away from their place of origin. This atmospheric transport is fast and spreads microbial cells across geographic barriers. It only takes days for them to cross continents and oceans, for example. In this article, we will explain which microbes are found in the air, where they come from, and the atmospheric factors that affect them.

WHAT ARE AIRBORNE MICROBES?

Microbes are tiny living organisms (also called microorganisms) ranging in size from a few millimeters (mm) to around 100 nanometers (nm)—so small they generally cannot be seen without a microscope. Microbes make up a majority of the living things on Earth and they are everywhere, from the deepest parts of the oceans to the highest mountains and even the atmosphere. Microbes must often deal with unique and often extreme conditions, such as very high and or low temperatures, UV radiation from the sun, high pressure in the deep ocean, high salinity in salt marshes, acidity in contaminated water, and darkness in caves. The atmosphere is one of the most extreme environments microbes can live in, so scientists' curiosity led to a research field called **aerobiology**. The earliest aerobiology studies over the ocean date back to the early 1800's, when Christian Gottfried Ehrenberg, one of the pioneers of microscopy, identified a few dozen single-celled organisms called **protists** from rainwater collected on the famous research vessel the *HMS Beagle*, while sailing in the Atlantic Ocean [1].

AEROBIOLOGY

The study of airborne biological particles. It encompasses the production, dispersal, and transport of airborne microbes and nutrients, and their impact on the environment and on human health.

PROTISTS

A diverse group of microorganisms with a nucleus that can cause diseases in humans and other animals, while others form beneficial relationships with other organisms.

The air we breathe contains nitrogen, oxygen, carbon dioxide, trace amounts of other gases, as well as aerosols. Aerosols refer to any type of particle in the air, including dust particles and **bioaerosols**, which are living or dead organisms and their remains. Bioaerosols are constantly released into the air and consist largely of viruses, bacteria, fungi, lichen, and protists, but also pollen and small seeds (Figure 1). Each day, hundreds of trillions of microbes are exchanged between the air and ocean [2], which highlights the importance of this process. Once in the air, many airborne microbes become attached to dust and other particles and are incorporated into water droplets in clouds, fog, rain, and snow. These conditions allow many airborne microbes to remain alive during their journey through the air [3], as they cross large distances and get deposited in areas they would otherwise not be able to reach. This is like a microbe taking an airplane trip from one continent to another.

BIOAEROSOLS

Tiny particles of biological origin that are suspended in the air, including bacteria, viruses, fungi, protozoa, and algae. These biological particles can be found virtually everywhere on Earth.

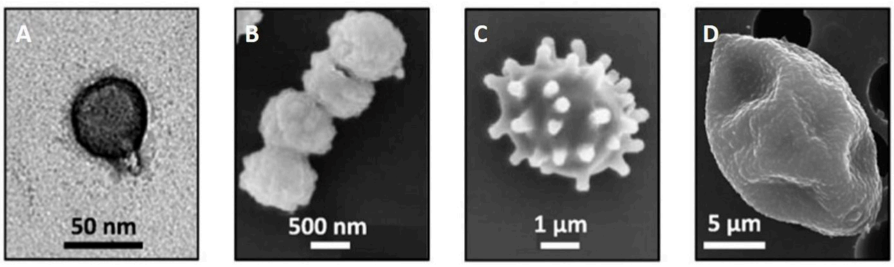

Figure 1

Figure 1

Electron microscopy images showing microbes common in atmospheric bioaerosols: **(A)** virus, **(B)** bacteria, **(C)** fungal spore, and **(D)** pollen grain. The bars indicate the size, where nm stands for nanometer (one billionth of a meter) and µm stands for micrometer (one millionth of a meter). Adopted from Fröhlich-Nowoisky et al. [4].

Deserts produce particularly large amounts of dust, which carries many microbes into the air. This is the case for the Sahara Desert (North Africa), the Arabian Desert (Middle East), the Gobi and the Taklamakan deserts (China), the Mojave Desert (southwestern United States), and the Atacama Desert (South America). Other processes that can result in airborne microbes being carried into the atmosphere include sea/lake spray from breaking waves, industrial activities, wildfires, and volcanic eruptions (Figure 2). Of these, the most surprising are wildfires. The air temperature near a fire's core can reach well over 1,000°C (1,800 °F). And yet, aerosols collected during wildfires carry ∼100,000 microbial cells in 1 m^3 of air (which is the same volume as a box with a length of 1 m on all sides). The abundance of airborne microbes during fires is about 10 times higher than the abundance of typical aerosols, such as dust particles.

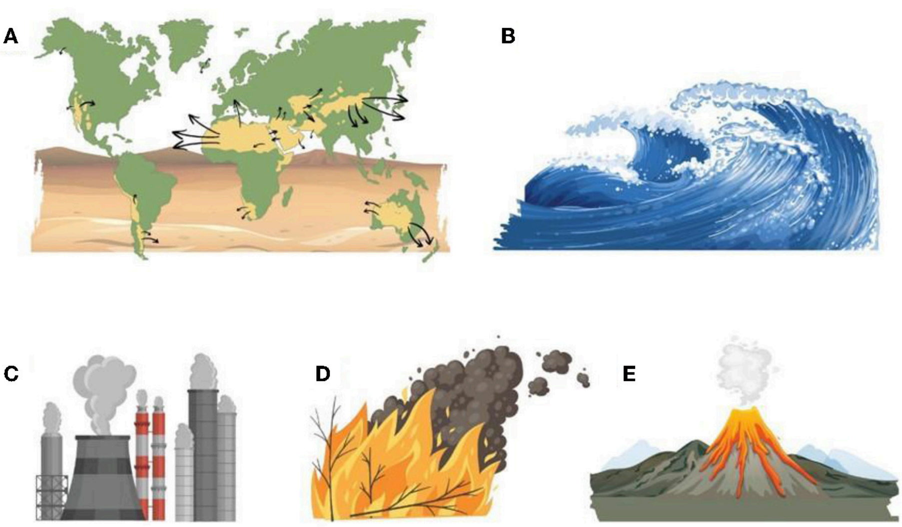

Figure 2

Figure 2

Important sources of dust and other particles in the air, called aerosols, include: **(A)** the great deserts, depicted in yellow; **(B)** sea spray; **(C)** industrial activities; **(D)** wildfires; and **(E)** volcanic eruptions.

HOW DO WE STUDY AIRBORNE MICROBES?

Atmospheric scientists, ecologists, and oceanographers use many techniques to collect and study airborne microbes. Each technique has its own strengths, limitations and specific use. For example, scientists can filter air using pumps, to collect and concentrate airborne microbes on filters. They can also culture the organisms, which means exposing a petri dish full of growth media to the air for a specified period of time, and then incubating it to grow the microbes. Finally, scientists can use a method called microbial impaction, which requires a device that cools and condenses the air sample, forcing the microbes to build up on a collection surface (Figures 3A–C). The airborne microbes collected with any of these techniques are then analyzed in the lab. Scientists can use instruments like microscopes to count cells (and even identify some of them), methods to study their growth and metabolism, and complex **molecular techniques** to study the diversity of airborne microbes based on their DNA (Figures 3D–F).

MOLECULAR TECHNIQUES

Laboratory methods used to analyze and manipulate molecules, including DNA, RNA, and proteins. Molecular techniques have a wide range of applications, including studying algal/animal diversity in each environment.

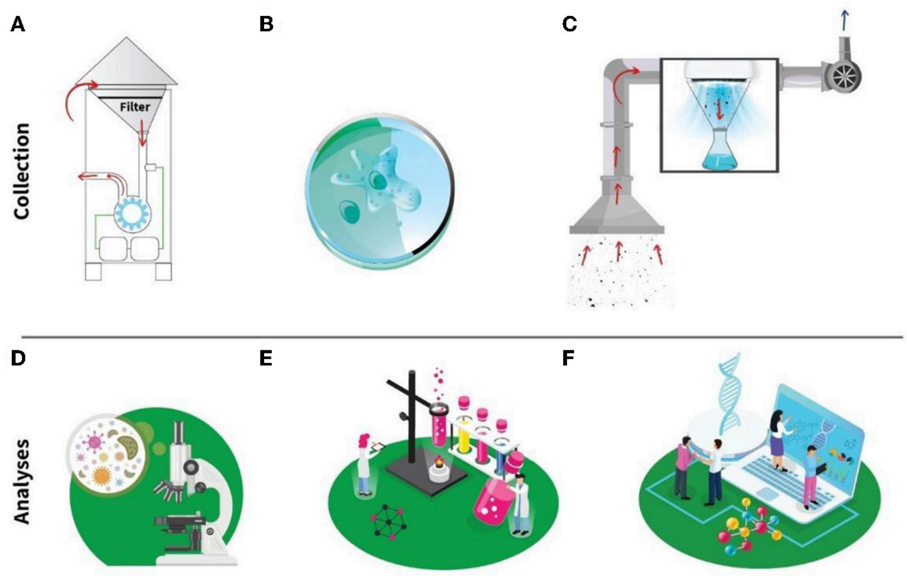

Figure 3

Figure 3

Several scientific approaches used to collect and analyze airborne microbes in the atmosphere. Collection methods include: **(A)** pumping air through filters to concentrate the microbes, **(B)** culturing (growing) the microbes, and **(C)** microbial impaction, which involves concentrating aerosols in liquid media. Analyses used to study the airborne microbes include: **(D)** various kinds of microscopes, **(E)**, culturing them in the lab, and **(F)** molecular techniques to look at their DNA.

WHICH ENVIRONMENTAL FACTORS AFFECT AIRBORNE MICROBES?

The number of airborne microbes can vary greatly. The atmosphere generally contains anywhere from 100 to 100,000 cells per cubic meter of air [2]. The diversity of airborne microbes is influenced by many environmental factors combined with human activities. These include air temperature, humidity, wind speed, wind direction, rain patterns, the time since airborne microbes were uplifted, time of year and time of day, and altitude. The diversity also depends on where the aerosol came from, since airborne microbes originate from land or water and can be produced from human activities like agriculture or industry. Note that similar factors also affect the diversity and viability of other microbes not transported in the air, such as those in acidic ponds and estuaries or in tide pools that often dry out. Therefore, we can learn a lot about how microbes cope with harsh environmental conditions by studying the factors affecting airborne microbes.

HOW DO AIRBORNE MICROBES SURVIVE IN THE ATMOSPHERE?

The interactions of airborne microbes with the atmosphere can have important ecological, climate, and human health consequences. For example, airborne bacteria are involved in the conversion of atmospheric gases into biologically usable forms, which can affect air quality and climate. Airborne microbes can also serve as surfaces around which raindrops can accumulate within clouds, thereby helping in cloud formation and precipitation patterns [5]. Some airborne microbes are adapted to cope with harsh atmospheric conditions, for example, by forming **spores** or producing substances that protect them from radiation or drying out. Some of these spores also have an aerodynamic shape that enables them to be transported through the air for very long distances. Airborne microbes also survive better when they shelter within dust particles, sea/lake spray, or clouds, where the conditions are more favorable because the humidity is higher and the damaging UV radiation is lower [3].

SPORES

Cells that can withstand very harsh conditions due to the protection of thick cell walls. Spores can later germinate and develop into new individuals when conditions improve.

WHAT HAPPENS WHEN AIRBORNE MICROBES LAND?

When airborne microbes are deposited back on the Earth's surface, they can influence the diversity and function of both water- and land-based ecosystems. How fast airborne microbes fall back to Earth, called deposition velocity, depends mainly on their size, shape, air temperature, humidity, and airflow. Typically, the deposition velocity of viruses is around a few mm per second, while for larger cells, such as algae, the velocity is in the order of several cm per second. The microbe's cell size determines how far it can be transported and how long it remains in the atmosphere. Landing back on Earth (land or ocean) can introduce new and potentially harmful microbes, like viruses, which can change the ecosystem in which they land. Airborne microbes can also have positive effects when they fertilize the ocean with **nutrients** that allow **phytoplankton** to grow. Phytoplankton are at the base of the marine **food web**, so they influence the abundance and diversity of all other organisms in the ocean, from snails and mussels to fish and whales. Airborne microbes can also contribute to harmful algal blooms in lakes, rivers, and the ocean. These blooms can be dangerous to animal and human health. For example, some airborne cyanobacteria (bacteria that are capable of producing oxygen through photosynthesis, just like plants) can release toxins into the air and water and cause a range of severe health effects, including liver and kidney damage, damage to the nerves and brain, and allergic reactions.

NUTRIENTS

Substances that organisms need to live, grow, and function properly. Aerosol particles contain a variety of nutrients such as nitrogen, phosphorus, and trace elements.

PHYTOPLANKTON

Microscopic organisms that live in aquatic environments, such as oceans, lakes, and rivers and can perform photosynthesis like plants. They are at the base of aquatic food webs.

FOOD WEB

The marine food chain is a hierarchical feeding relationship where phytoplankton are eaten by primary consumers such as zooplankton, which are then eaten by larger organisms such as small fish.

THE FUTURE OF BIOAEROSOL RESEARCH

As Earth's climate changes and more areas become dry and desert-like, dust loads in the atmosphere will increase, and storm events will become more frequent and last longer. This will boost long-distance air transport of bioaerosols, and therefore it is very important to understand microbial aerial transport, and the complex relationships that exist between the atmosphere, land, and sea—not only what those relationships are like *today* but also what they might be like in coming decades. Maybe one day *you* will be leading a big project to study bioaersols and make exciting discoveries.

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YOUNG REVIEWERS

HARMONY, AGE: 12

My name is Harmony and I live with one bunny, shelffuls of books, 100's of birds and squirrels to share my backyard with. My dream is to be a marine biologist and an ornithologist. Some of my hobbies are bird photography, hiking, reading, and booping my bunny. I have published two fantasy books about animals to give people a window into the secret and sometimes very unfair lives of animals.

SHRIYA, AGE: 13

Hi, my name is Shriya. I live in the U.S. I am in eighth grade, and my favorite subjects are science and math. In my free time, I like to dance and do art. I just started working with Frontiers for Young Minds, and am very excited to continue!

AUTHORS

EYAL RAHAV

I am a biological oceanographer. In recent years I have studied how dust-borne microbes interact with microbial communities inhabiting the surface oceans. I am intrigued by cats. In my spare time, I love to cook and watch *Seinfeld* and *Curb your Enthusiasm* reruns. *eyal.rahav@ocean.org.il

BARAK HERUT

As a geochemist, my main interests are research on aerosols, marine pollution, and chemical oceanography, focusing on the atmospheric and aquatic ecosystems. In my free time I like traveling and hiking. Lately I have learned to enjoy a wide variety of wines—thus merging good spirit with research, both based on microorganisms.

ADINA PAYTAN

I am a scientist working at the University of California, Santa Cruz. My work focuses on understanding Earth processes and the interactions between the land-ocean-atmosphere so I can contribute to conservation. I love diving, hiking, and traveling to see cool places around the world.