**MICROBIAL BIOTECHNOLOGY**

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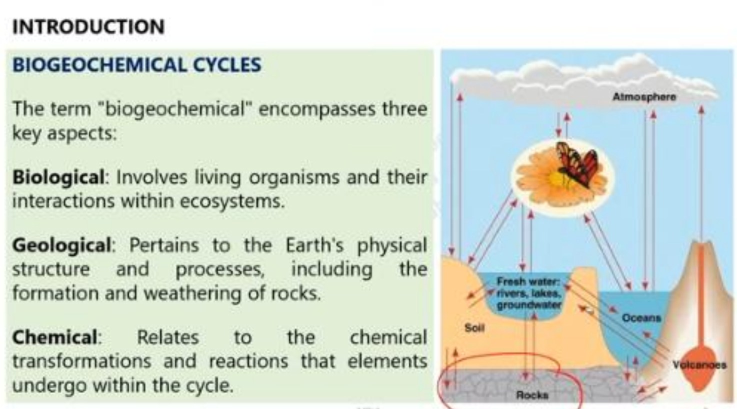
**Lecture-26**
**Lec 26: Microbial ecology, biogeochemical cycles**

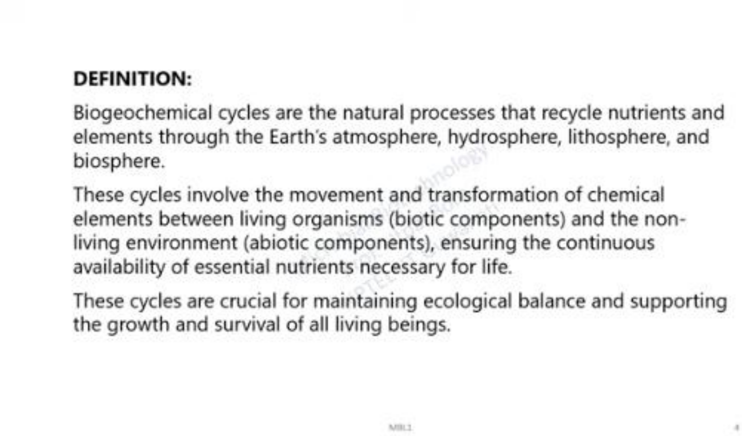
Hello friends, welcome to my course on microbial biotechnology. Today, we are starting module number 8 on environmental biotechnology, where we will begin with a lecture on microbial ecology and biogeochemical cycles. Briefly, we have three broad sections here, starting with a background and introduction. Then, we will have an overview of biogeochemical cycles and study some of them in detail. We will also discuss the role of microbes in biogeochemical cycles.

So, the term 'biogeochemical' encompasses three key aspects. Number one is the biological, second is the geological, and third is the chemical. Biological involves living organisms and their interactions with ecosystems. Geological pertains to the Earth's physical structure and processes, including the formation and weathering of rocks. The chemical relates to the transformations and reactions that elements undergo within the cycle.

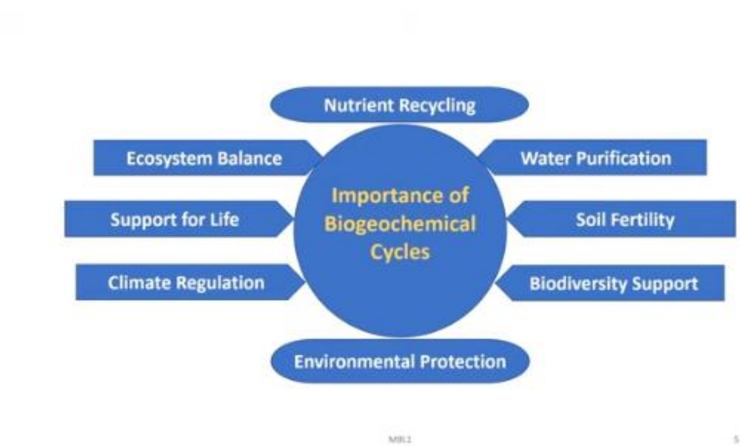



To start with a definition, biogeochemical cycles are natural processes that recycle nutrients and elements through Earth's atmosphere, hydrosphere, lithosphere, and biosphere. These cycles involve the movement and transformation of chemical elements between living organisms (the biotic components) and the non-living environment (the abiotic components), ensuring the continuous availability of essential nutrients necessary for life.

They are crucial for maintaining ecological balance and supporting the growth and survival of all living beings. So, what is the importance of biogeochemical cycles?

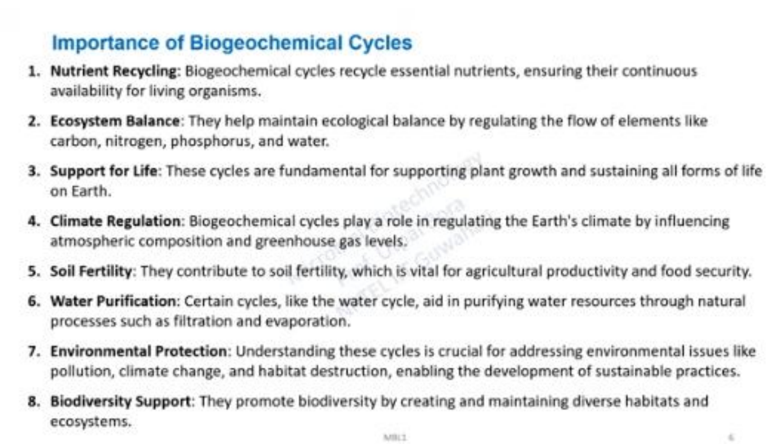



So, we will discuss them one by one under different headings. One of the most important aspects of biogeochemical cycles is nutrient recycling. They also help in water purification, maintain soil fertility, support biodiversity, and protect the environment. They play a huge role in climate regulation and, overall, support life and maintain the balance of the ecosystem. When it comes to nutrient recycling, which we will discuss in a little more detail,

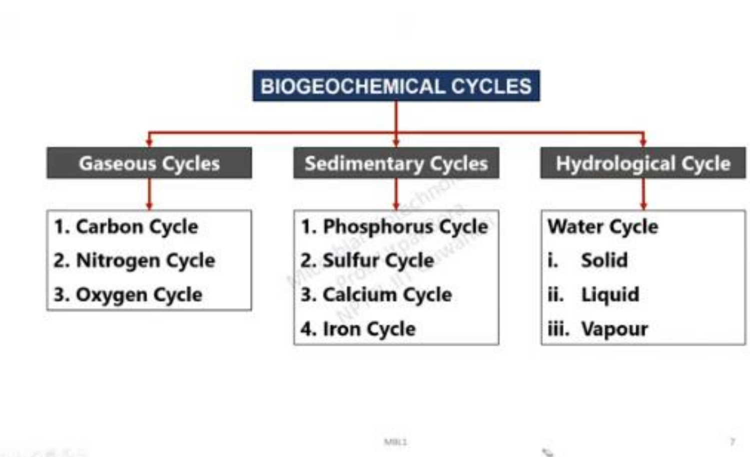



Biogeochemical cycles recycle essential nutrients, ensuring their continuous availability for living organisms. They balance the ecosystem by maintaining ecological equilibrium through regulating the flow of elements like carbon, nitrogen, phosphorus, and water. They support life. These cycles are fundamental for plant growth and sustaining all forms of life on Earth. They also regulate the climate by playing a role in Earth's climate by influencing atmospheric composition and greenhouse gas levels. They contribute to soil fertility, which is vital for agricultural productivity and food security.

Certain cycles, like the water cycle in particular, aid in purifying water resources through natural processes such as filtration and evaporation. They protect the environment. Understanding these cycles is crucial for addressing environmental issues like pollution, climate change, and habitat destruction, enabling the development of sustainable practices. They also support biodiversity. They promote biological diversity by creating and maintaining diverse habitats and ecosystems.

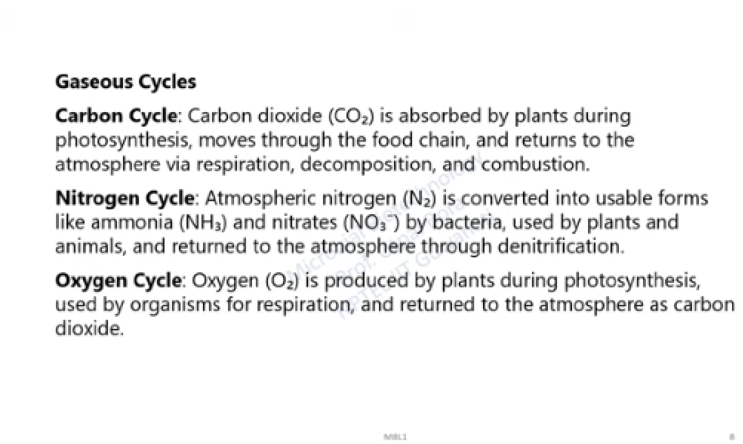



We can divide the biogeochemical cycles into three broad types. One are the gaseous cycles comprising of carbon, nitrogen, and oxygen. Then we have the sedimentary cycles, phosphorus, sulfur, calcium, and iron. Then we have the hydrological cycle, mostly the water cycle, which comprises of the solid, ice, the liquid, and the vapor phase. So, we will discuss some of these in this lecture today.



So, let us start with the gaseous cycles overall. The carbon cycle, carbon dioxide is absorbed by plants during photosynthesis which is known to you also certain photosynthetic bacteria. They move through the food chain and return to the atmosphere via respiration, decomposition and combustion. Then there is the nitrogen cycle where atmospheric nitrogen is converted into usable forms like ammonia and nitrates by bacteria used by plants and animals and returned to the atmosphere through denitrification where microbes are involved. Then there is the oxygen cycle.

This is produced by plants during photosynthesis, used by organisms for respiration and return to the atmosphere as carbon dioxide. Then there are the sedimentary cycles where phosphorus is released from rocks through the process of weathering. These are absorbed by plants, transferred through the food chain and returned to the soil through decomposition. Then we have the sulphur cycle which is again released from rocks assimilated by plants and microbes passed through the food chain and returned to the environment through decomposition and microbial processes. Calcium moves between the earth's crust, water bodies and living organisms, essential for bone formation and cell wall stabilization.




The iron cycles between the Earth's crust, oceans, and living organisms. It is crucial for oxygen transfer in blood and as a nutrient for plants and microorganisms. The water cycle is crucial for all life forms, involving the movement of water through various reservoirs: liquid water in rivers, lakes, and oceans; ice and glaciers in polar caps; and water vapor in the atmosphere. It transports nutrients and supports biogeochemical cycles through processes like precipitation, evaporation, and runoff, which are all essential for ecosystem health. So, here we see two figures: one shows us the ecosystem services, and the other shows us the ecosystem disservices.

**Sedimentary Cycles**

**Phosphorus Cycle**: Phosphorus is released from rocks through weathering, absorbed by plants, transferred through the food chain, and returned to the soil through decomposition.

**Sulfur Cycle**: Sulfur is released from rocks, assimilated by plants and microbes, passed through the food chain, and returned to the environment through decomposition and microbial processes.

**Calcium Cycle**: Calcium moves between the earth's crust, water bodies, and living organisms, essential for bone formation and cell wall stabilization.

**Iron Cycle**: Iron cycles between the earth's crust, oceans, and living organisms, crucial for oxygen transport in blood and as a nutrient for plants and microorganisms.

**Hydrological Cycle (Water Cycle)**

The water cycle is crucial for all life forms, involving the movement of water through various reservoirs: liquid water in rivers, lakes, and oceans; ice in glaciers and polar caps; and water vapor in the atmosphere.

It transports nutrients and supports biogeochemical cycles through processes like precipitation, evaporation, and runoff, all essential for ecosystem health.

So, this is a theoretical representation of the main biogeochemical flows. Then, the intermediate and final ecosystem services are connected to a healthy ecosystem structure. So, this one is a healthy ecosystem structure, and this is a damaged ecosystem structure. So, let us try to understand these two theoretical frameworks. So, we have biogeochemical cycles.

As represented by carbon, nitrogen, and water over here, in both the damaged ecosystem and the healthy ecosystem. So, the healthy ecosystem structure will support carbon dioxide sequestration, and it will also help in biological fixation and, of course, percolation. But in the damaged ecosystem, it will actually result in carbon dioxide emissions. Then, there is leaching and runoff, and there is also surface runoff of all the important nutrients we have discussed. So, as a result of these, the final outcome in a healthy ecosystem is positive.

We have very positive climate regulation; there is enhanced food production, better soil formation, and soil with healthy properties. Then, there is sufficient water supply, and floods are also controlled. And there are many other such positive ecosystem services. But in a damaged ecosystem structure, which may happen due to anthropogenic activities or even certain natural calamities, it leads to climate change. For example, you're consuming more fossil fuels, which release greenhouse gases, or due to the industrialization process, which is not green. Then, because the ecosystem is damaged, it will not be able to produce enough food, so there will be food scarcity and even famine.

And then there will be soil erosion. For example, due to deforestation, the soil will be impacted very badly. There will be water scarcity, and there will be erratic flooding from time to time. There is also erratic rainfall, which we can see in climate change and extreme weather events. So, from these two comparisons, we understand that a healthy balance of the biogeochemical cycle is very, very important in maintaining the health of the ecosystem, which will be able to provide us better ecosystem services. And if we fail to maintain that, it actually results in ecosystem disservices, and this can ruin many nations.

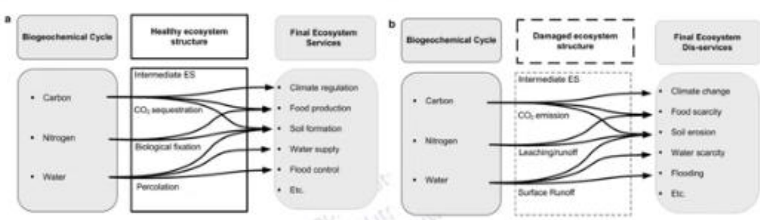



Fig. 1. (a) Theoretical representation of main biogeochemical flows, intermediate and final ES connected to a healthy ecosystem structure. (b) Theoretical representation of main biogeochemical flows and final environmental dis-services provided by a damaged ecosystem structure.

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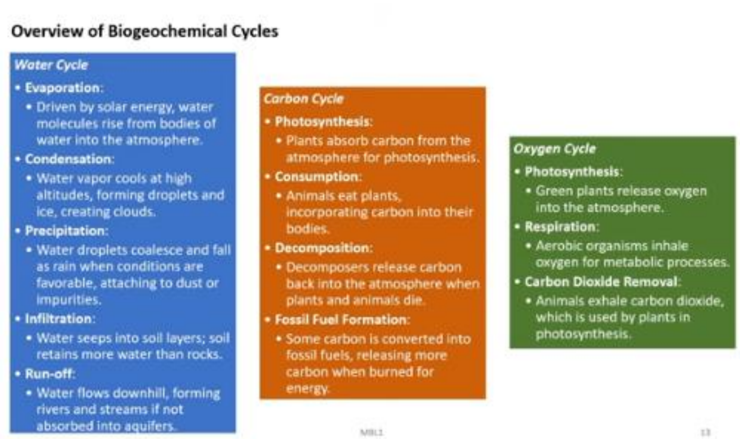
So, it is in our interest; we need to understand these biogeochemical cycles and the intricate balance in nature among the various cycles. So, let us now go to section 2, where we will have an overview of the biogeochemical cycles, which we have mentioned very briefly in the earlier slides. So, the water cycle comprises evaporation due to the heating of water bodies by the sun or solar energy. Water molecules will rise from them into the atmosphere. which is known to you, and there will be condensation. As the water vapor moves into higher altitudes, it will cool down and form droplets and ice, creating clouds. Finally, they will precipitate; the water droplets coalesce and fall as rain when conditions are favorable, attaching to dust or impurities.

Then this water seeps into soil layers. Soil retains more water than rocks. Then there may be runoff. Water flows downhill, forming rivers and streams if not absorbed into the aquifers. Then there is the carbon cycle, where due to photosynthesis, plants and photosynthetic microorganisms absorb carbon from the atmosphere and fix it as carbon dioxide.

Then these are consumed by animals, and they incorporate the carbon into their bodies. So the flow of carbon from the atmosphere through the plant body by the process of photosynthesis to the animal happens by this pathway in this cycle. And when these organisms die, they decompose. There will be microbes that decompose them, releasing the carbon back into the atmosphere. And then some may also result in fossil fuel formation.

Some carbon is converted into fossil fuels, releasing more carbon when burned for energy. Such events have occurred in the past history of our planet, and the fossil fuels we use today are a result of these kinds of reactions. Then there is the oxygen cycle, which is closely related to the photosynthetic process of the carbon cycle. Green plants release oxygen into the atmosphere. And then there is respiration, where this oxygen will be used.

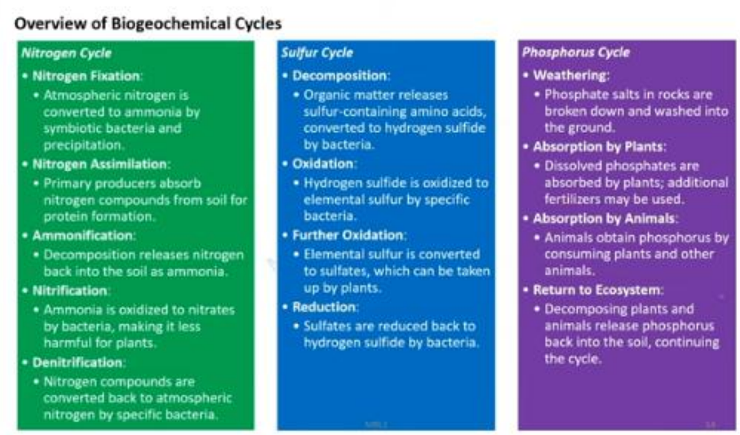
Particularly the aerobic organisms inhale oxygen for the metabolic processes and the animals exhale the carbon dioxide which is used by plants in photosynthesis. Then we have the nitrogen cycle, sulfur cycle and the phosphorus cycle. Nitrogen basically exists as a gas in the atmosphere which is converted to ammonia by symbiotic bacteria and then some of them also are done fixed by natural methods which we will discuss in some of the slides later. The primary producers then absorb nitrogen compounds from soil for protein formation. And then there is ammonification, where decomposition releases nitrogen back into the soil as ammonia.




And then there is nitrification, where ammonia is oxidized to nitrites by bacteria, making it less harmful for plants. And finally, there will be also denitrification, where nitrogen compounds are converted back to atmospheric nitrogen by specific bacteria. In the sulfur cycle, decomposition occurs on the dead matter. So, these organic matter releases sulfur-containing amino acids converting to hydrogen sulfide where microbes like bacteria are involved. And then they are oxidized.

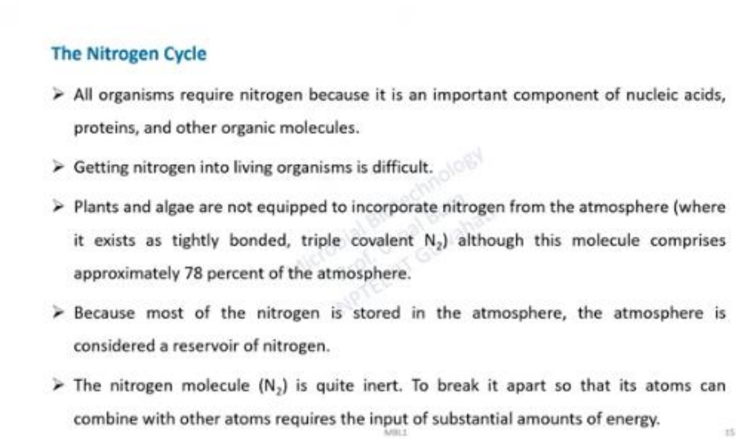
Hydrogen sulfide is oxidized to elemental sulfur by specific bacteria. And further elemental sulfur is converted to sulfates which can be taken up by plants. And then there is a reduction where sulfates are reduced back to hydrogen sulfate by bacteria. Then we have the phosphorus cycle. Phosphorus unlike nitrogen do not exist in the gaseous form.

It exists in the rocks. The phosphate salts in rocks are broken down and washed into the ground. They are absorbed by plants after they dissolve, and then we may also add an external supply of phosphorus through fertilizer application. Then, these are obtained by animals by consuming plants or other animals. And then, decomposed organisms, plants, and animals release phosphorus back into the soil, continuing the cycle or closing the loop.

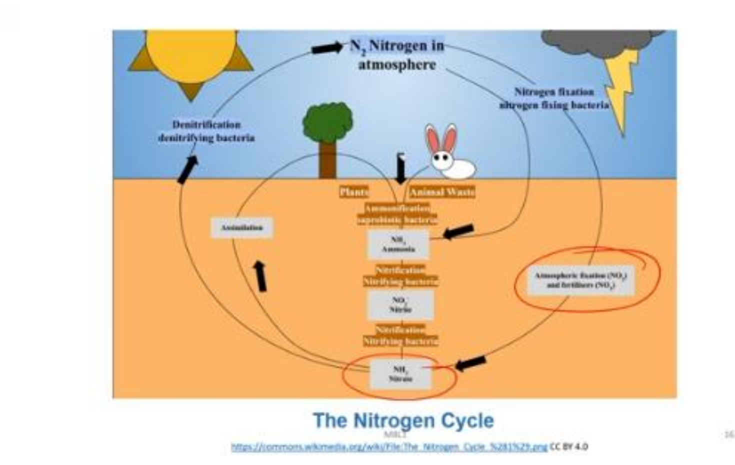



Let us discuss a little more about the nitrogen cycle. All organisms require nitrogen because it is an important component of nucleic acids, proteins, and many other organic molecules. But since it exists in gaseous form, it is difficult for living organisms to absorb nitrogen easily. Plants and algae are not equipped to incorporate nitrogen from the atmosphere, where it exists as tightly bonded triple covalent molecules, although these comprise approximately 78% of the atmosphere. Because most nitrogen is stored in the atmosphere, the atmosphere is considered a reservoir of nitrogen.

The nitrogen molecule is therefore quite inert. So, as it has a triple bond, as mentioned, breaking these bonds apart— so that its atoms can combine with other atoms—requires a substantial input of energy. So, here we can see that nitrogen in the atmosphere, which is quite high—close to around 78%— Then, in spite of its abundance, it is not easily or readily available for absorption by plants and algae.

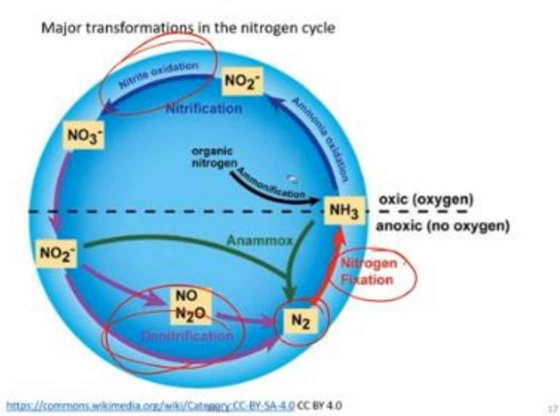



So, these are mediated by the presence of certain bacteria which we call as nitrogen fixes. So, these atmospheric nitrogen can be fixed and then converted into nitrate and then they are further converted by nitrifying bacteria into nitrite and ammonia and then finally become available to this organism. Then there are also certain denitrifying microbes which will release these nitrates back into the atmosphere. So, in this way the nitrogen is recycled between the atmosphere and the biosphere with the help of bacteria both in fixing it and releasing it.

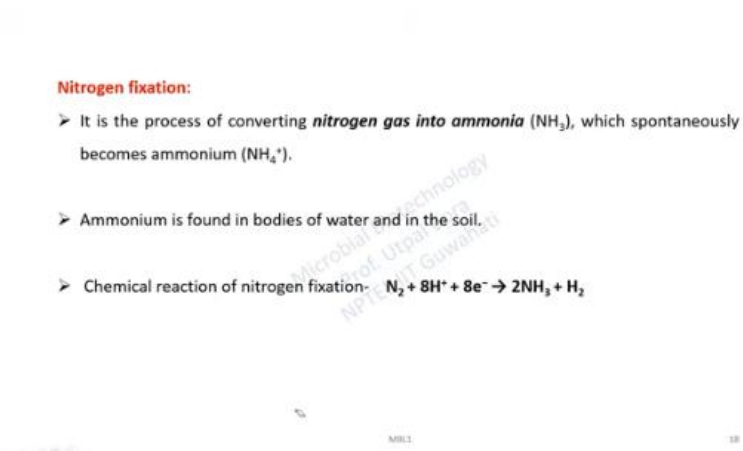



So, some major transformations in the nitrogen cycle, this cycle we have discussed earlier in some of the slides briefly. So, these atmospheric nitrogen is getting fixed and then producing ammonia which is oxidized and then further production of the nitrite which is further oxidized and then due to denitrifying bacteria it is again getting released. So, there are two other important pathways in this cycle, the anammox and also the ammonification.

So, we will be starting about these various arms of this cycle in detail. So, nitrogen fixation is therefore a process of converting nitrogen gas into ammonia which spontaneously becomes ammonium.




It is found in bodies of water and also in the soil. And we can see the chemical reaction of nitrogen fixation where nitrogen gas reacts with 8 hydrogen ions and with the presence of 8 electrons and converted into ammonia and hydrogen. However, there are three processes which help in fixing this nitrogen in the biosphere from the atmosphere. So, number one is the atmospheric fixation. This is a natural process.



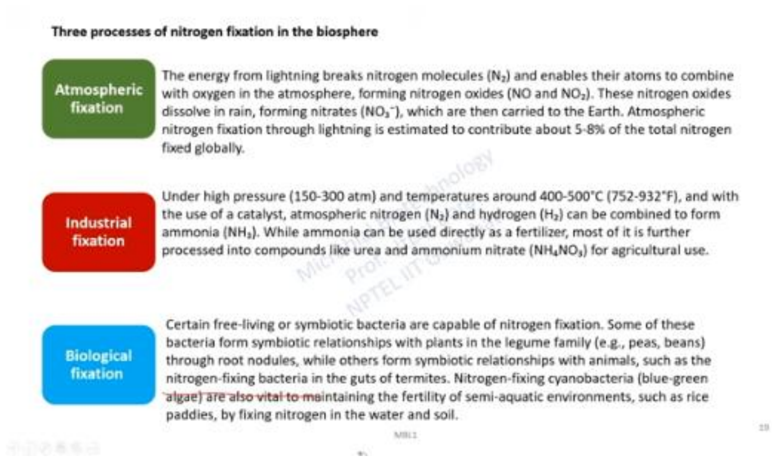

The other one is biological fixation. That is also a natural process where biotic components are involved. And then there is a man-made process, which is industrial nitrogen fixation. Let us study them one by one. So, as we have discussed, it is very difficult to break the nitrogen molecule into atoms, and it requires very high energy.

So, this energy in the atmosphere comes from lightning, which breaks down the nitrogen molecule. And thereby, it enables the atoms to combine with oxygen in the atmosphere to form nitrogen oxides. These oxides dissolve in rain, forming nitrates, which are then carried to the earth along with precipitation. The atmospheric nitrogen fixation through lightning is estimated to contribute about 5-8% of the total nitrogen fixed globally. So whenever there is a thunderstorm or lightning, although it is dangerous and may be fatal to trees, humans, and animals, it carries out an important ecosystem service of converting nitrogen into nitrogen oxides, thereby also dissolving along with rainwater and falling into art

in the form of nitrates. And these account for around 5-8% of the total nitrogen fixed globally. Now, to fix this nitrogen in the atmosphere, we would need very large industries if we want to do it artificially. Because in the industrial fixation of nitrogen, we need very high pressure—150 to 300 atmospheres—and very high temperatures around 400 to 500 degrees centigrade. And also, we need certain catalysts where atmospheric nitrogen and hydrogen can be combined to form ammonia.

While ammonia can be used directly as a fertilizer, most of it is further processed into compounds like urea and ammonium nitrate for ease of agricultural use. So, we can see that this is a very expensive process. Then, there is a third process of nitrogen fixation. Where certain free-living or symbiotic bacteria are capable of nitrogen fixation. Some of these bacteria form symbiotic relationships with plants in the legume family, like peas and beans, through the root nodules, while others form symbiotic relationships with animals, such as the nitrogen-fixing bacteria in the gut of termites.

So, the nitrogen-fixing cyanobacteria, blue-green algae, are also vital to maintaining the fertility of semi-aquatic environments, such as rice fields, where they fix nitrogen in the water as well as the aquatic phase. So, this table lists some of the prokaryotes known to carry out nitrogen fixation. So, the majority of them are, as you can see, bacteria, and they are mostly free-living, aerobic, and phototrophic. But there are also certain archaea which are free-living, anaerobic, and chemolithotrophic, like Methanosarcina and Methanococcus. Then, we also have bacteria which are free-living but anaerobic phototrophic, like Chromatium and Chlorobium, and then we also have Clostridium.




Then, we have Rhizobium and Frankia, which are symbiotic, aerobic, chemo-organotrophic microorganisms that carry out nitrogen fixation. So, Nostoc and Anabaena are cyanobacteria, which are free-living, aerobic, and phototrophic, whereas Pseudomonas and Azotobacter are free-living, aerobic, chemo-organotrophic bacteria that fix nitrogen. Nitrogen assimilation. Primary producers absorb nitrogen compounds from the soil for protein formation. Then, there is ammonification, where decomposition releases nitrogen back into the soil as ammonia.

**Representative prokaryotes known to carry out nitrogen fixation**

| Genus | Phylogenetic Affiliation | Lifestyle |
|---|---|---|
| *Nostoc, Anabaena* | Bacteria (Cyanobacteria) | Free-living, aerobic, phototrophic |
| *Pseudomonas, Azotobacter, Methylomonas* | Bacteria | Free-living, aerobic, chemoorganotrophic |
| *Alcaligenes, Thibacillus* | Bacteria | Free-living, aerobic, chemolithotrophic |
| *Methanosarcina, Methanococcus* | Archaea | Free-living, anaerobic, chemolithotrophic |
| *Chromatium, Chlorobium* | Bacteria | Free-living, anaerobic, phototrohic |
| *Desulfovibrio, Clostridium* | Bacteria | Free-living, anaerobic, chemoorganotrophic |
| *Rhizobium, Frankia* | Bacteria | Symbiotic, aerobic, chemoorganotrophic |

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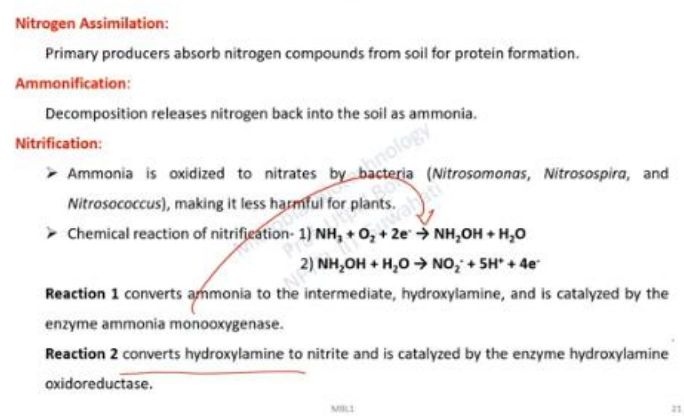
Bernhard, A. (2010) The Nitrogen Cycle: Processes, Players, and Human Impact. Nature Education Knowledge 3(10):25

In nitrification, ammonia is oxidized to nitrates by bacteria like Nitrosomonas, Nitrosospira and Nitrosococcus, thereby reducing the harmfulness of the compound for plants. The chemical reaction for nitrification shows ammonia being oxidized and then, in the next step, reacting with water to release nitrates. The overall reaction converts ammonia to intermediate hydroxylamine, catalyzed by an enzyme called ammonia monooxygenase, and then hydroxylamine is converted to nitrite by the enzyme hydroxylamine oxidoreductase in step 2. The second step in nitrification is the oxidation of nitrite to nitrate, where one nitrite molecule reacts with half an oxygen molecule to produce one nitrate compound. This is carried out by a completely separate group of prokaryotes known as nitrate-oxidizing bacteria, such as Nitrospira, Nitrobacter, Nitrococcus, and Nitrospina. Then comes denitrification, which involves two steps. The first reaction represents the reduction of



**Nitrogen Assimilation:**

Primary producers absorb nitrogen compounds from soil for protein formation.

**Ammonification:**

Decomposition releases nitrogen back into the soil as ammonia.

**Nitrification:**

- Ammonia is oxidized to nitrates by bacteria (*Nitrosomonas*, *Nitrosospira*, and *Nitrosococcus*), making it less harmful for plants.
- Chemical reaction of nitrification- 1) $NH_3 + O_2 + 2e^- \rightarrow NH_2OH + H_2O$

  2) $NH_2OH + H_2O \rightarrow NO_2^- + 5H^+ + 4e^-$

**Reaction 1** converts ammonia to the intermediate, hydroxylamine, and is catalyzed by the enzyme ammonia monooxygenase.

**Reaction 2** converts hydroxylamine to nitrite and is catalyzed by the enzyme hydroxylamine oxidoreductase.

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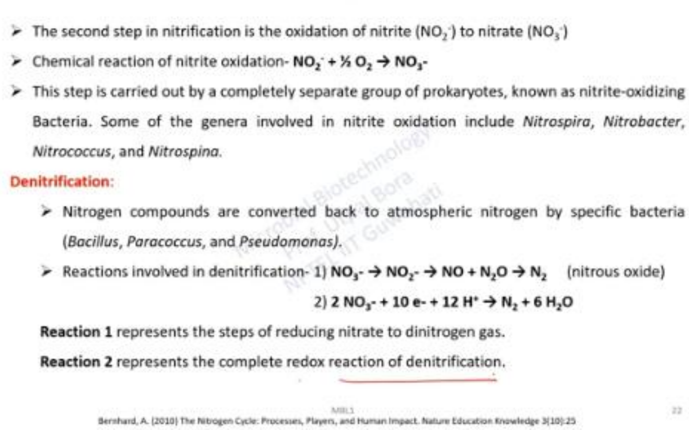
nitrate to dinitrogen gas, and the second step represents the complete redox reaction of denitrification. Here, nitrogen compounds are converted back to atmospheric nitrogen by specific bacteria like Bacillus, Paracoccus, and Pseudomonas. Anammox, or anaerobic ammonia oxidation, is carried out by prokaryotes belonging to Planctomycetes, a phylum of bacteria. This was first described in the bacterium Brocadia anammoxidans. These anaerobic bacteria oxidize ammonia by using nitrate as the electron acceptor to produce gaseous nitrogen.



- The second step in nitrification is the oxidation of nitrite ($NO_2^-$) to nitrate ($NO_3^-$)
- Chemical reaction of nitrite oxidation- $NO_2^- + ½ O_2 \rightarrow NO_3$-
- This step is carried out by a completely separate group of prokaryotes, known as nitrite-oxidizing Bacteria. Some of the genera involved in nitrite oxidation include *Nitrospira*, *Nitrobacter*, *Nitrococcus*, and *Nitrospina*.

**Denitrification:**

- Nitrogen compounds are converted back to atmospheric nitrogen by specific bacteria (*Bacillus*, *Paracoccus*, and *Pseudomonas*).
- Reactions involved in denitrification- 1) $NO_3$- $\rightarrow$ $NO_2$- $\rightarrow NO + N_2O \rightarrow N_2$ (nitrous oxide)

  2) $2\ NO_3$- + 10 e- + $12\ H^+ \rightarrow N_2 + 6\ H_2O$

**Reaction 1** represents the steps of reducing nitrate to dinitrogen gas.

**Reaction 2** represents the complete redox reaction of denitrification.

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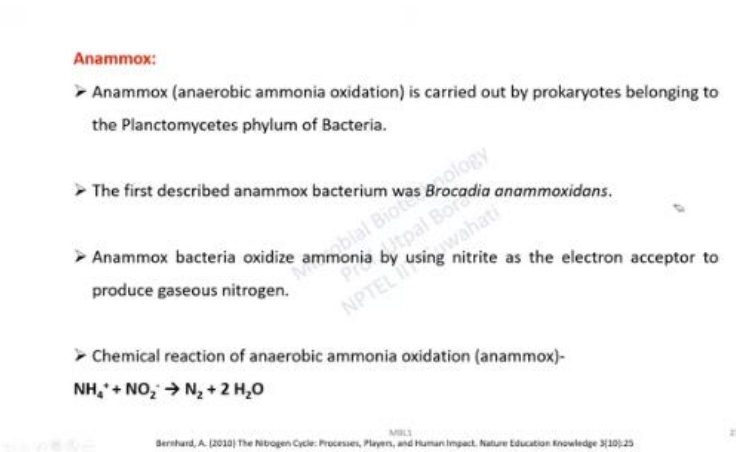
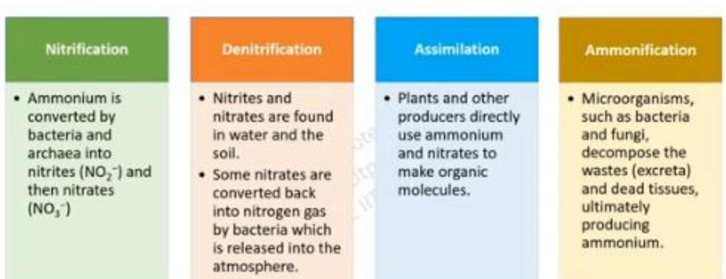
Bernhard, A. (2010) The Nitrogen Cycle: Processes, Players, and Human Impact. Nature Education Knowledge 3(10):25

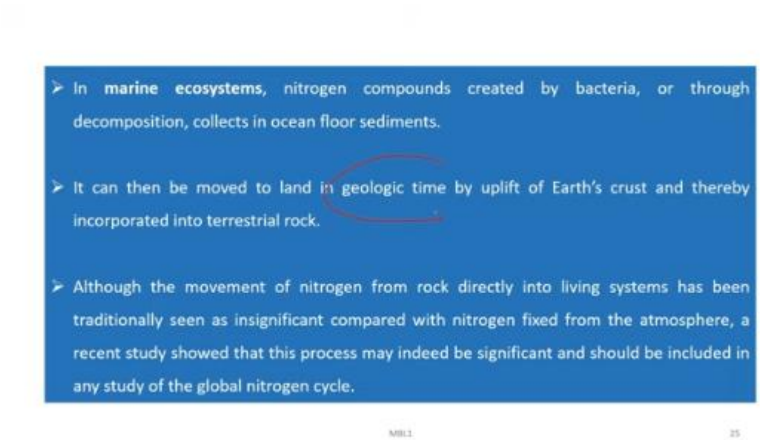
So here you can see the chemical reaction of anaerobic nitrogen oxidation where ammonia gas is produced and there is also a release of water. So overall, these processes include nitrification, denitrification, assimilation, and ammonification, where different kinds of bacteria are involved. So, in nitrification, ammonium is converted by bacteria and archaea into nitrites and then nitrates. In denitrification, nitrites and nitrates are found in water and soil. Some of these are converted back into nitrogen gas by bacteria, which is released into the atmosphere.



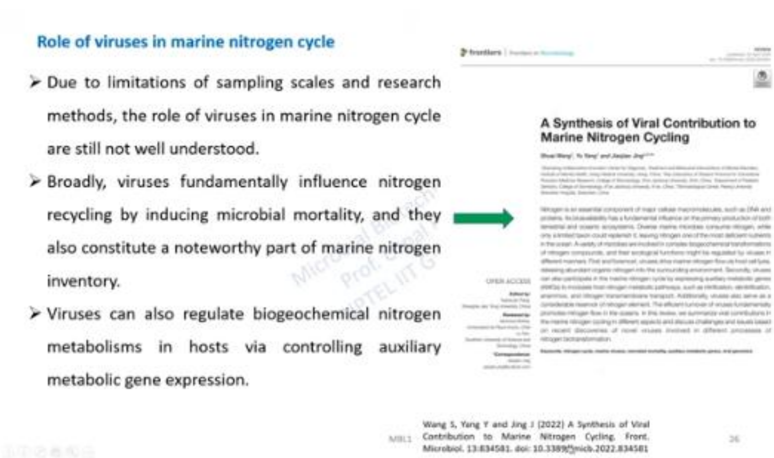

In assimilation, plants and other producers directly use ammonium and nitrates to make organic molecules, and in ammonification, microorganisms such as bacteria and fungi decompose waste and dead tissues to produce ammonium. In marine ecosystems, nitrogen compounds created by bacteria or through decomposition collect in the ocean floor sediments. It can be removed or transported to land in geologic time, which will be a very, very long time. This event occurs by the uplift of Earth's crust, thereby incorporating it into terrestrial rock. The movement of nitrogen from rock directly into living systems has been considered insignificant compared with nitrogen fixed from the atmosphere.



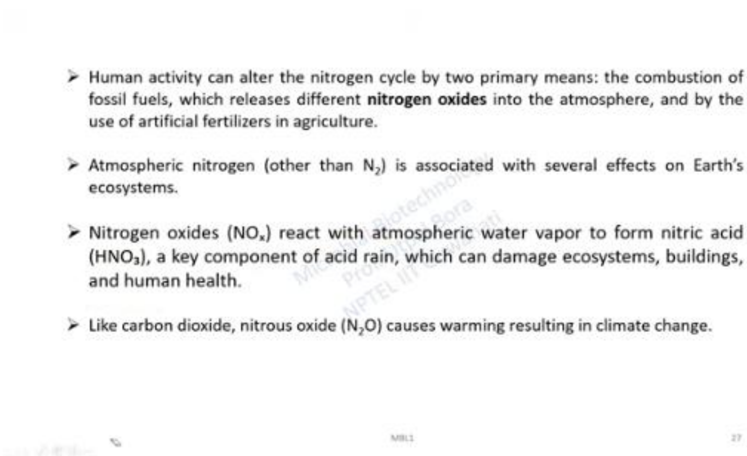
But a recent study has shown that this process may indeed be significant and should be included in the study of the global nitrogen cycle. Viruses also play a role in the marine nitrogen cycle. So, this 2022 review sums up the synthesis of viral contributions to marine nitrogen cycling. Here, due to limitations in sampling techniques and research methods, the role of viruses in the marine nitrogen cycle is not well understood. Broadly, viruses fundamentally influence nitrogen recycling by inducing microbial mortality, and they also constitute a noteworthy part of the marine nitrogen inventory.

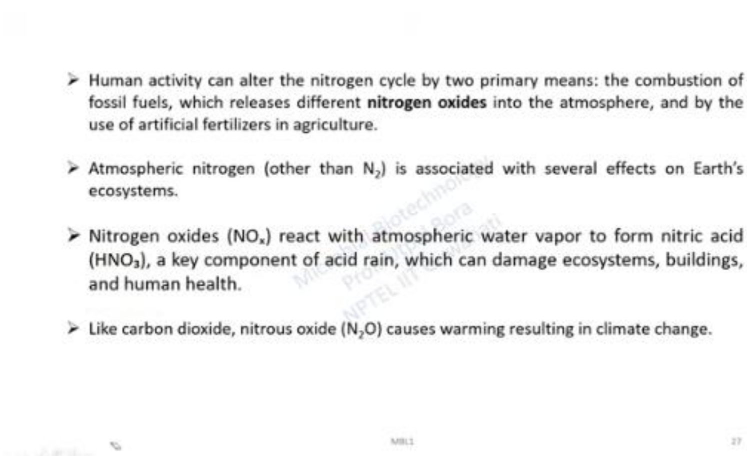



Viruses regulate biogeochemical nitrogen metabolism in hosts by controlling auxiliary metabolic gene expression. Human activity can also alter the nitrogen cycle in two ways. Number one, the combustion of fossil fuels releases different nitrogen oxides into the atmosphere, and number two, the use of artificial fertilizers in agriculture. Atmospheric nitrogen, other than nitrogen gas, is associated with several effects on Earth's ecosystem. Nitrogen oxides react with atmospheric water vapor to form nitric acid, a key component of acid rain, which can damage ecosystems, buildings, or building materials like marble and stone, and also affect human health.



Like carbon dioxide, nitrous oxide causes global warming, resulting in climate change. Another human intervention that alters the nitrogen cycle is the application of fertilizers, which are washed into lakes, streams, and rivers by surface runoff, resulting in saltwater and freshwater eutrophication, a process whereby nutrient runoff causes the overgrowth of algae, depletion of oxygen, and death of aquatic fauna. Harmful algal blooms, dead zones, and fish kills occur as a result of this eutrophication. This begins with the increased load of nutrients to estuaries and coastal waters.




For example, the Mississippi River carries millions of tons of nutrient-rich sediment into the Gulf each year, thereby causing havoc. Here, you can see dead fish killed by toxins or oxygen depletion in a lake in Iowa called Lake Binder. This picture, taken in 2007, illustrates the severe eutrophication of Dianchi Lake as a result of polluted runoff. Dianchi is China's fifth-largest freshwater lake, but its water is undrinkable. Due to severe pollution, this has led to persistent algal blooms and hypoxia.

- Fertilizers are washed into lakes, streams, and rivers by surface runoff, resulting in saltwater and freshwater **eutrophication**, a process whereby nutrient runoff causes the overgrowth of algae, the depletion of oxygen, and death of aquatic fauna.

Harmful algal blooms, dead zones, and fish kills are the results of a process called eutrophication—which begins with the increased load of nutrients to estuaries and coastal waters. The Mississippi River carries millions of tons of nutrient-rich sediment into the Gulf each year.

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Dead fish resulting from toxins or oxygen depletion in Lake Binder, Iowa.
Photo Credit: Dr. Jennifer L. Graham | U.S. Geological Survey


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Taken in 2007, this picture illustrates the severe eutrophication of Dianchi Lake as a result of polluted runoff. Diancht is China's fifth largest freshwater lake, but its water is undrinkable because of severe pollution which has led to persistent algal blooms and hypoxia.

Photo Credit: Greenpeace China

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Let us now discuss the phosphorus cycle. Several forms of nitrogen, such as nitrogen gas, ammonia, and nitrates, are involved in the nitrogen cycle. While phosphorus mainly exists in the form of phosphate ions in the phosphorus cycle, unlike the nitrogen cycle, phosphorus has no gaseous form in the atmosphere. Phosphorus is essential for the synthesis of nucleic acids and phospholipids, which are key components of biological membranes. Rocks serve as a major reservoir for phosphorus, much of which originates from ocean sediments.

## The Phosphorus Cycle

- Several forms of nitrogen (such as nitrogen gas, ammonium, and nitrates) are involved in the nitrogen cycle, while phosphorus mainly exists in the form of the phosphate ion ($PO_4^{3-}$) in the phosphorus cycle.
- Unlike the nitrogen cycle, phosphorus has no gaseous form in the atmosphere.
- Phosphorus is essential for the synthesis of nucleic acids and phospholipids, which are key components of biological membranes.



Phosphate-containing ocean sediments form primarily from the remains and excretion of marine organisms. In addition, volcanic ash aerosols and mineral dust can also contribute to phosphates. Over geological time, these sediments are moved to land through the uplifting of Earth's surface. The movement of phosphate from the ocean to land and through the soil is extremely slow, as in the case of nitrogen we discussed, with the average phosphate ion having a residence time in the ocean of 20,000 to 100,000 years. The weathering of rocks releases phosphates into the soil and bodies of water.

- Rocks serve as a major reservoir for phosphorus, much of which originates from ocean sediments.
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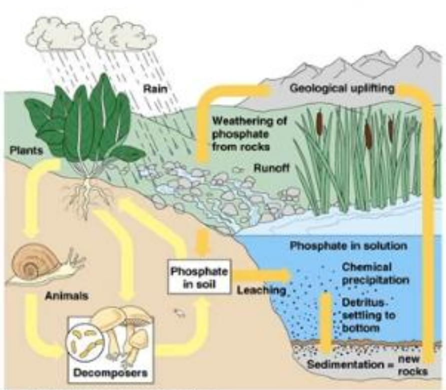
Plants assimilate phosphates in the soil and incorporate them into organic molecules, making phosphorus available to consumers in terrestrial food webs. Waste and dead organisms are decomposed by fungi and bacteria, releasing phosphates back into the soil. Some phosphate is lost from the soil, entering rivers, lakes, and the oceans. Primary producers in aquatic food webs, such as algae and photosynthetic bacteria, assimilate phosphate, making organic phosphate available to consumers in aquatic food webs. Similar to terrestrial food webs, phosphorus is reciprocally exchanged between phosphate dissolved in the ocean and organic phosphorus in marine organisms.

- **Weathering** of rocks releases phosphates into the soil and bodies of water.
- Plants can assimilate phosphates in the soil and incorporate it into organic molecules, making phosphorus available to consumers in terrestrial food webs.
- Waste and dead organisms are decomposed by fungi and bacteria, releasing phosphates back into the soil.
- Some phosphate is **leached** from the soil, entering into rivers, lakes, and the ocean.
- Primary producers in **aquatic food webs**, such as algae and photosynthetic bacteria, assimilate phosphate making organic phosphate available to consumers in aquatic food webs. Similar to **terrestrial food webs**, phosphorus is reciprocally exchanged between phosphate dissolved in the ocean and organic phosphorus in marine organisms.

So, this is the phosphorus cycle, where we can see the geological uplifting from the ocean bed. It goes up to the rock due to geological events. Mostly, it remains in rocks, which may again form due to sedimentation from the solution phase, as you can see over here. The phosphate in soil is also released into this aquatic phase and then may be sedimented. And then it is mostly released from the weathering of phosphate from the rocks. And then these are directly taken up by plants and made available to animals. Also, the decomposers release them back into the soil. So basically, there is weathering, then absorption by plants and absorption by elements, and the return to the ecosystem by the decomposers.




The Phosphorus Cycle

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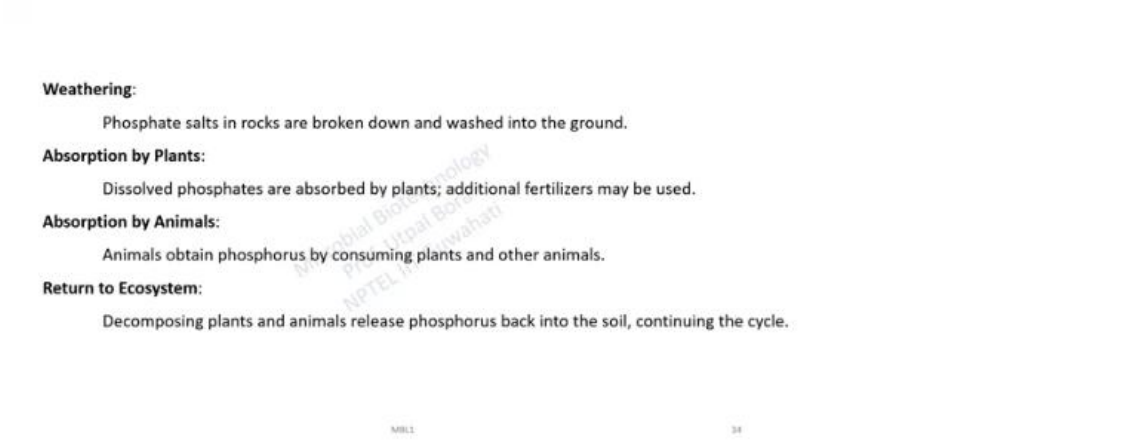
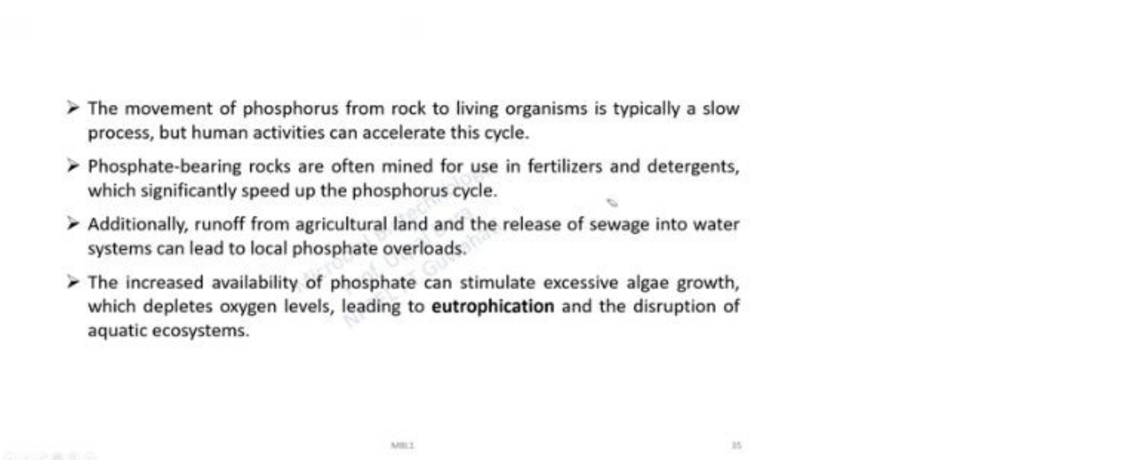
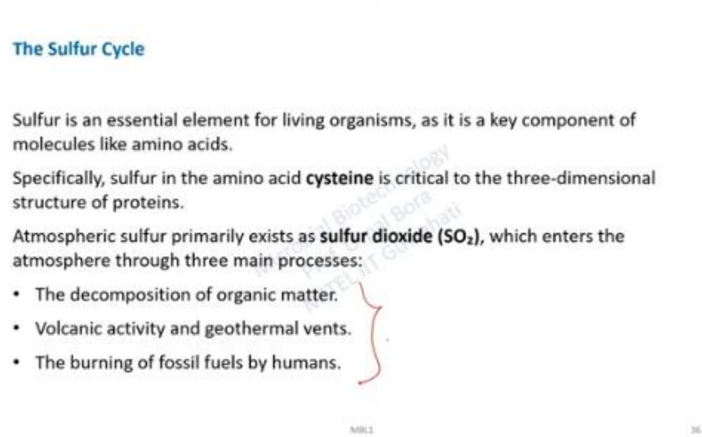



The movement of phosphorus from rock to living organisms is typically a slow process, as we have already discussed, but human activities can accelerate this cycle. Phosphate-bearing rocks are often mined by humans for use in fertilizers and detergents, which significantly speeds up the phosphorus cycle. Accelerated runoff from agricultural land and the release of sewage into water systems can lead to local phosphate overloads. The increased availability of phosphate can stimulate excessive algae growth, which depletes oxygen levels, leading to problems like eutrophication and the disruption of the aquatic system, and may result in fish kills. Another important cycle is the sulfur cycle.

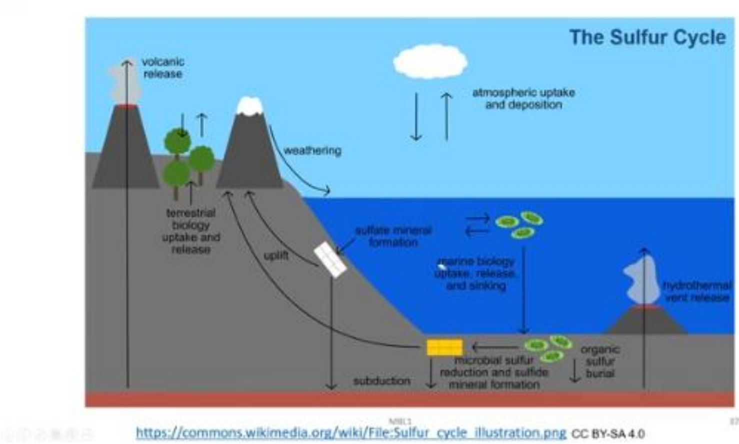



Sulfur is an essential element for living beings. It is a key component of molecules like proteins, where it helps in the formation of disulfide and it is critical to the three-dimensional structure of the proteins. Atmospheric sulfur primarily exists as sulfur dioxide, which enters the atmosphere through three main processes: the decomposition of organic matter, volcanic activity and geothermal vents, and the burning of fossil fuels by humans.



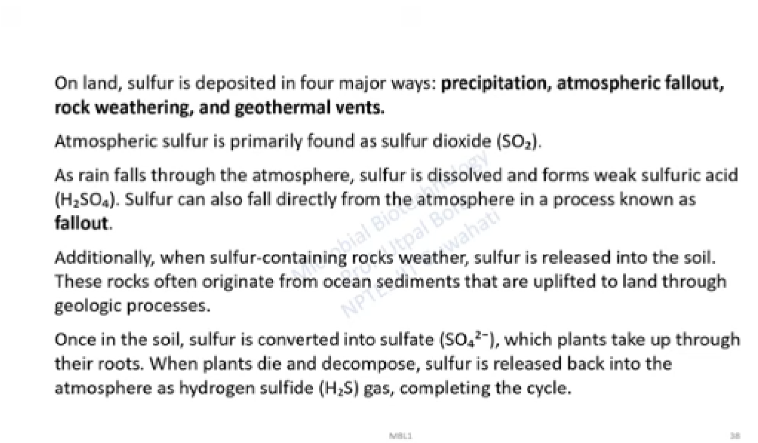

So, this is the sulfur cycle. You can see the volcanic release, as well as release by weathering and terrestrial biology uptake and release. These all leach out into the water bodies. There, we also have sulfate mineral formation, and there is sulfate uplift, as we can see, or it may also go for subduction, as shown here. There is marine biology uptake and release by certain organisms, and there is also sinking here.

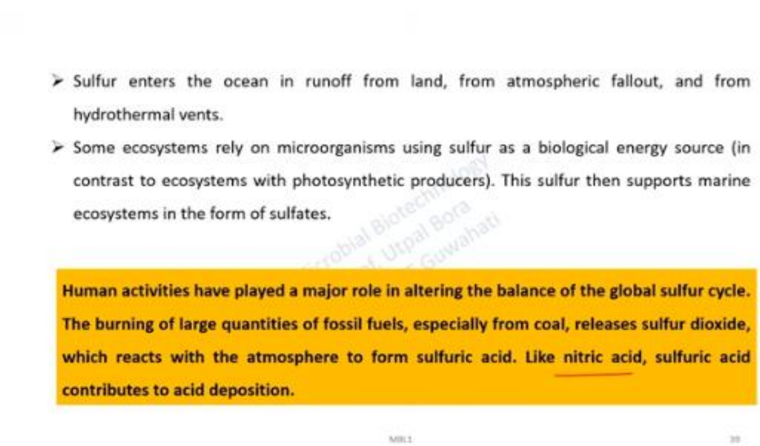
Then we have organic sulfur burial in many cases, and these are also released undersea by hydrothermal vent activity, along with atmospheric uptake and decomposition. This is the overall sulfur cycle. All land sulfur is deposited in four main ways: by precipitation, atmospheric fallout, rock weathering, and geothermal vents. Atmospheric sulfur is primarily found as sulfur dioxide. As rain falls through the atmosphere, sulfur dissolves and forms weak sulfuric acid.




Sulfur can also fall directly from the atmosphere in a process known as fallout. Additionally, when sulfur-containing rocks weather, sulfur is released into the soil. These rocks often originate from ocean sediments that are uplifted to land through geologic processes. Once in the soil, sulfur is converted into sulfate, which plants take up through their roots.

When plants die and decompose, sulfur is released back into the atmosphere as hydrogen sulfide gas, thereby completing the cycle. So, human activities have played a major role in altering the balance of the global sulfur cycle. The burning of large quantities of fossil fuels, especially coal, releases sulfur dioxide, which reacts with the atmosphere to form sulfuric acid. Like nitric acid, sulfuric acid contributes to acid deposition. Now let us discuss the role of microbes in biogeochemical cycles.

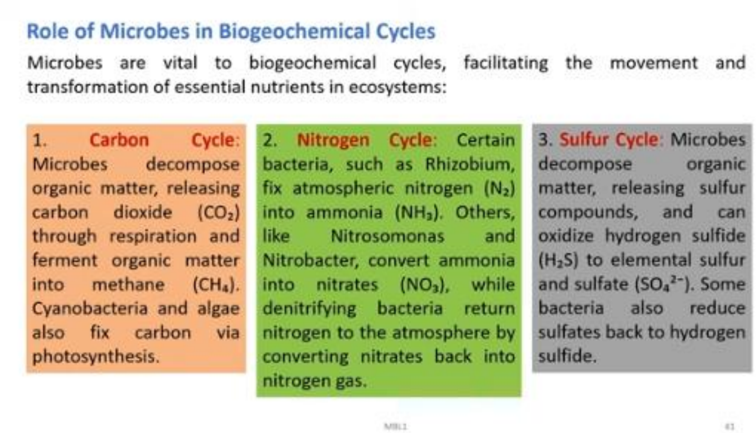


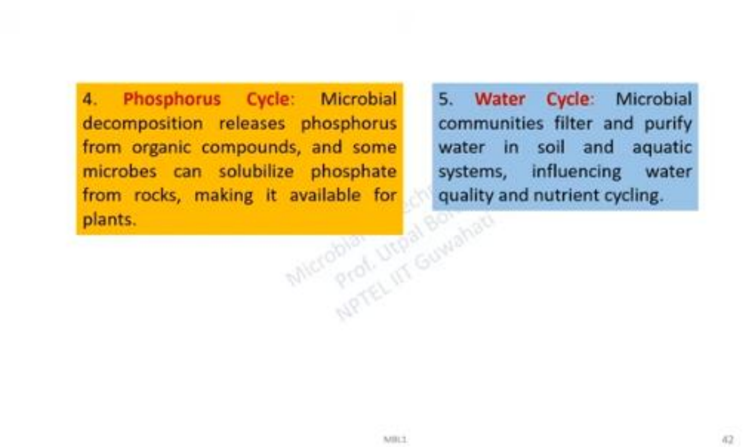




So, we know about the various biogeochemical cycles, and microbes are very vital to these cycles, whereby they facilitate the movement and transformation of essential nutrients in the ecosystem. For example, in the carbon cycle, microbes decompose organic matter, release carbon dioxide through respiration, and ferment organic matter into methane. Cyanobacteria and algae also fix carbon via photosynthesis. In the nitrogen cycle, certain bacteria, such as Rhizobium, fix atmospheric nitrogen into ammonia. Others, like

Nitrosomonas and Nitrobacter, convert ammonia into nitrates, while denitrifying bacteria return nitrogen to the atmosphere by converting nitrates back into nitrogen gas.

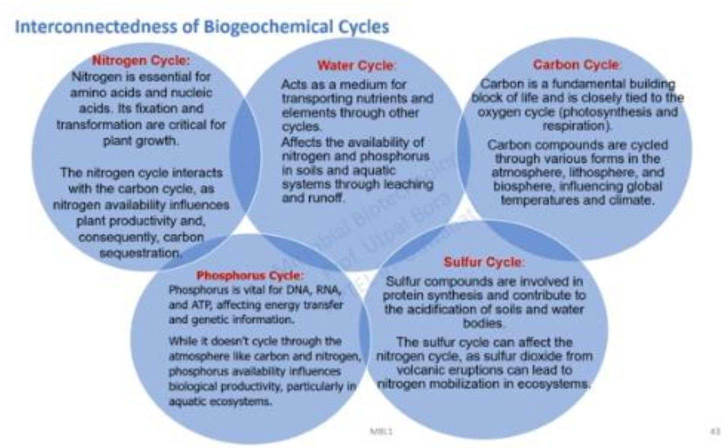
In the sulfur cycle, microbes decompose organic matter, releasing sulfur compounds, and can oxidize hydrogen sulfide to elemental sulfur and sulfate. Some bacteria also reduce sulfates back to hydrogen sulfide. In the phosphorus cycle, microbial decomposition releases phosphorus from organic compounds, and some microbes can solubilize phosphate from rocks, making it available for plants. While in the water cycle, microbial communities filter and purify water in soil and aquatic systems, influencing water quality and nutrient cycling. All these biogeochemical cycles work independently of one another, but they are also interconnected in several ways.




For example, the nitrogen cycle interacts with the carbon cycle as nitrogen availability influences plant productivity and consequently carbon sequestration. The water cycle acts as the medium for transporting nutrients and elements through other cycles. So, it is very essential, as the functioning of other cycles depends on the water cycle. It affects the availability of nitrogen and phosphorus in soils and aquatic systems through leaching and runoff. When it comes to the carbon cycle, carbon is a fundamental building block of life and closely tied to the oxygen cycle, photosynthesis, and respiration.

And the carbon compounds cycle in various forms in the atmosphere, lithosphere, and biosphere, influencing global temperatures and climate. Similarly, sulfur compounds are involved in protein synthesis and contribute to the acidification of soils and water bodies. The sulfur cycle can affect the nitrogen cycle, as sulfur dioxide from volcanic eruptions can lead to nitrogen mobilization in ecosystems. And when it comes to the phosphorus cycle, phosphorus does not cycle through the atmosphere like carbon and nitrogen. Phosphorus availability influences biological productivity, particularly in aquatic systems, and thereby it will determine the cycling of nitrogen, carbon, and sulfur.




So, what is the relationship between biochemical cycles and the health of ecosystems or ecology? It is a very fundamental relationship because these cycles define the interactions and processes that sustain ecosystems. So, let us look into how biogeochemical cycles define ecology. Number one, they define nutrient availability. Biogeochemical cycles regulate the flow of essential nutrients like carbon, nitrogen, phosphorus, and sulfur, which are crucial for the growth and reproduction of organisms.

The availability of these nutrients directly influences primary productivity and the structure of food webs. They also dictate ecosystem functioning. The cycling of nutrients supports various ecological processes such as decomposition, primary production, and energy transfer. For example, the nitrogen cycle affects plant growth, which in turn supports herbivores and higher trophic levels. They support biodiversity.

### Biogeochemical Cycles and Ecology

The relationship between biogeochemical cycles and ecology is fundamental, as these cycles define the interactions and processes that sustain ecosystems.

#### (A) How Biogeochemical Cycles Define Ecology?

**Nutrient Availability:**

Biogeochemical cycles regulate the flow of essential nutrients like carbon, nitrogen, phosphorus, and sulfur, which are crucial for the growth and reproduction of organisms. The availability of these nutrients directly influences primary productivity and the structure of food webs.

**Ecosystem Functioning:**

The cycling of nutrients supports various ecological processes, such as decomposition, primary production, and energy transfer. For example, the nitrogen cycle affects plant growth, which in turn supports herbivores and higher trophic levels.

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Different ecosystems have varying nutrient dynamics influenced by biogeochemical cycles. For instance, nutrient-rich environments often support greater biodiversity, while poor nutrient systems may limit the types of species that can thrive. It dictates the energy flow. Biogeochemical cycles facilitate the flow of energy through ecosystems. For instance, the carbon cycle enables photosynthesis in plants.

This captures solar energy and converts it into chemical energy, forming the basis of food chains. When certain environmental conditions are influenced, the cycle affects physical and chemical conditions within the ecosystem, such as soil pH, moisture, and temperature. These factors, in turn, affect the types of organisms that can survive and flourish in a given habitat. So, any kind of imbalance in these cycles will thereby result in an unhealthy ecosystem and will also result in ecosystem disservices, as we have discussed earlier. Now, let us look from the other perspective: how ecology influences biogeochemical cycles.

**Biodiversity:**

Different ecosystems have varying nutrient dynamics influenced by biogeochemical cycles. For instance, nutrient-rich environments often support greater biodiversity, while nutrient-poor systems may limit the types of species that can thrive.

**Energy Flow:**

Biogeochemical cycles facilitate the flow of energy through ecosystems. For instance, the carbon cycle enables photosynthesis in plants, which captures solar energy and converts it into chemical energy, forming the basis for food chains.

**Environmental Conditions:**

The cycles influence physical and chemical conditions within ecosystems, such as soil pH, moisture, and temperature. These factors, in turn, affect the types of organisms that can survive and flourish in a given habitat.

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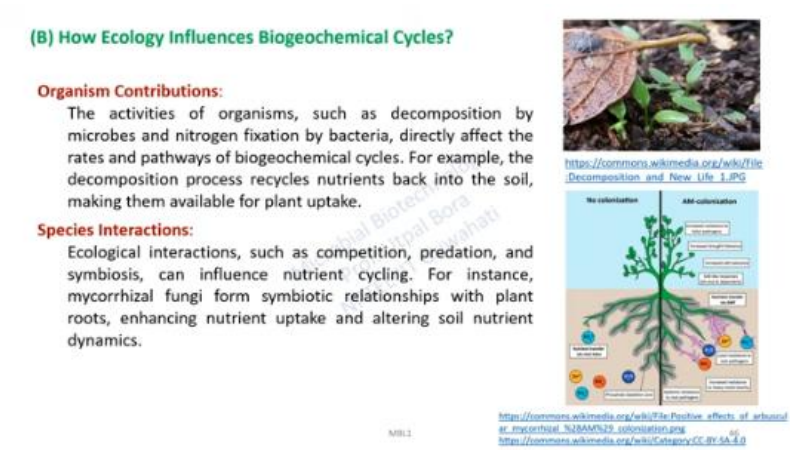
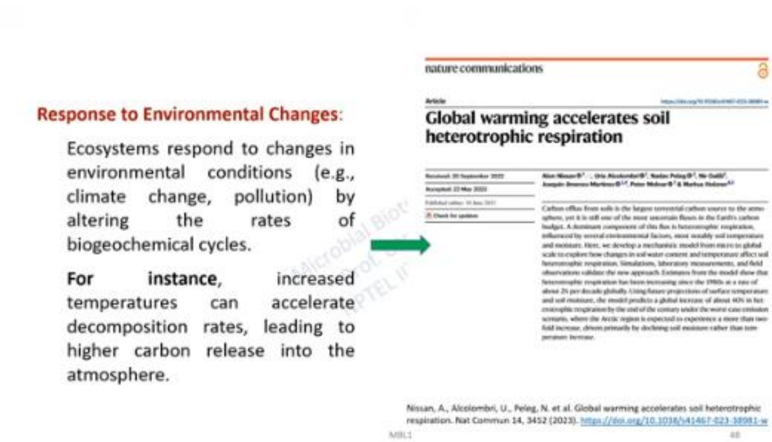
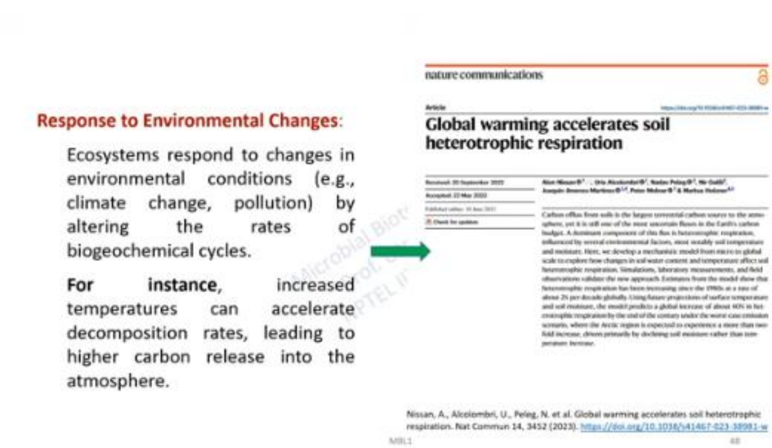
The organisms and their activities have a huge impact on the ecology and biogeochemical cycles. Activities of organisms, such as decomposition by microbes and nitrogen fixation by bacteria, directly affect the rates and pathways of biogeochemical cycles. For example, the decomposition process recycles nutrients back into the soil, making them available for plant uptake. There are species interactions, or ecological interactions, such as competition, predation, and symbiosis, which influence nutrient recycling. For instance, mycorrhizal fungi form symbiotic relationships with plant roots, enhancing nutrient uptake and altering soil nutrient dynamics.




So, there is habitat modification by organisms that modify their environments in ways that affect biogeochemical cycles. For example, beavers create wetlands that influence the hydrological cycle and nutrient retention, impacting surrounding ecosystems. Then, there is a response to environmental changes. Ecosystems respond to changes in environmental conditions, like climate change and pollution, by altering the rates of biogeochemical cycles. For instance, increased temperatures can accelerate decomposition rates, leading to higher carbon release into the atmosphere.




So, global warming will be impacted. So, here is a report on global warming, which is related to soil heterotrophic respiration. Finally, let us discuss the impact of humans. Human activities, such as agriculture, urbanization, and pollution, significantly impact both biogeochemical cycles and ecological integrity. For example, the use of fertilizers and pesticides affects the nitrogen and phosphorus cycles, leading to nutrient runoff and eutrophication in aquatic systems.




So, there are now reports such as these where excessive application of chemical fertilizers and pesticides has induced total phosphorus loss from planting, causing surface water eutrophication. So, with this, we come to the end of this lecture. Thank you for your patient hearing.

**Human Impact**:

Human activities, such as agriculture, urbanization, and pollution, significantly impact both biogeochemical cycles and ecological integrity.

**For example**, the use of fertilizers affects the nitrogen and phosphorus cycles, leading to nutrient runoff and eutrophication in aquatic systems.

scientific reports

OPEN Excessive application of chemical fertilizer and organophosphorus pesticides induced total phosphorus loss from planting causing surface water eutrophication

Liu, L., Zheng, X., Wei, X. et al. Excessive application of chemical fertilizer and organophosphorus pesticides induced total phosphorus loss from planting causing surface water eutrophication. Sci Rep 11, 23015 (2021). https://doi.org/10.1038/s41598-021-02521-7