DP IB Environmental Systems & Societies (ESS): SL

2.3 Biogeochemical Cycles

Contents

Biogeochemical Cycles

Introduction to Biogeochemical Cycles

- Biogeochemical cycles are natural processes that **circulate** the **chemical elements** necessary for **life**
  - They include cycles such as:
    - The carbon cycle
    - The nitrogen cycle
    - The hydrological cycle
  - These cycles ensure that these elements continue to be **available** to living organisms
  - This means they play a very important role in maintaining the balance of ecosystems and supporting life on Earth

Human impact

- Human activities such as burning fossil fuels, deforestation, urbanisation and agriculture can **disrupt** biogeochemical cycles
  - This can lead to environmental **imbalances** and threaten the **sustainability** of ecosystems
    - For example, deforestation can disrupt the carbon cycle by reducing the number of trees available to absorb carbon dioxide from the atmosphere

Components of biogeochemical cycles

- Biogeochemical cycles are made up of:
  - Stores
  - Sinks
  - Sources

- **Stores**:
  - Also known as **storages**
  - They are "reservoirs" where elements are held for varying periods of time
  - They represent areas where the element remains in **equilibrium** with the environment i.e. the **total input** of the element is **equal** to the **total output**
  - Examples include oceans, atmosphere, soil and living organisms
    - For example, the ocean serves as a major store of carbon in the carbon cycle, with dissolved carbon dioxide being absorbed by seawater
    - At the same time, an equivalent amount of carbon dioxide is released back into the atmosphere, maintaining equilibrium
  - They can either be **natural** or **artificial**
- **Sinks**:
  - Sinks represent parts of the cycle where a particular element **accumulates** over time
  - They are areas where the **total input** of the element is **greater than** the **total output**
    - This results in the **net accumulation** of the element
    - For example, fossil fuel deposits act as sinks for carbon in the carbon cycle, storing carbon that was once part of living organisms
  - They can either be **natural** or **artificial**
- **Sources**:
  - Sources **release** elements into the cycle
  - They represent parts of the cycle where the **total output** of the element is **greater than** the **total input**
    - This results in **net release** of the element
    - For example, volcanic eruptions release large amounts of carbon dioxide into the atmosphere, acting as a source in the carbon cycle
  - They can either be **natural** or **artificial**

Carbon Cycle

- Many different **materials** cycle through the abiotic and biotic components of an ecosystem
  - All materials in the living world are **recycled** to provide the building blocks for future organisms
- Elements such as **carbon** are **not limitless** resources
  - There is a finite amount of each element on the planet
  - Elements need to be recycled in order to allow new organisms to be made and grow
- Carbon is constantly being recycled around the **biosphere** so that the total amount of carbon in the biosphere is essentially **constant**
  - Carbon is transferred from one form to another by the various processes in the carbon cycle

Organic and inorganic carbon stores

- Organisms, crude oil and natural gas contain organic stores of carbon
  - Organic stores refer to the carbon-containing compounds found in organisms and fossil fuels
  - For example, carbon in these stores may exist as carbohydrates in organisms or hydrocarbons in fossil fuels
- Inorganic stores exist in the atmosphere, soils and oceans
  - Inorganic stores refer to reservoirs of carbon that exist in other non-living components of the biosphere
  - For example, carbon in these stores may exist as carbon dioxide or carbonates

Equilibrium and residence time

- A carbon store is in **equilibrium** when absorption (uptake) is **balanced** by the release
  - For example, the carbon stored in trees through photosynthesis is balanced by the carbon released during respiration
- **Residence time** is the average time that a carbon atom **remains** in a **store**
  - Without human interference like mining, the residence time in fossil fuels would be measured in hundreds of millions of years

Carbon flows in ecosystems

- Carbon flows between stores in ecosystems through various processes
- The main processes include:
  - **Photosynthesis** (transformation)—plants absorb CO_2 and convert it into organic compounds (carbohydrates)
  - **Cellular respiration** (transformation)—both plants and animals release CO_2 during respiration
  - **Feeding** (transfer)—animals consume organic matter, transferring carbon through the food chain
  - **Defecation** (transfer)—carbon is returned to the soil through waste products
  - **Death** and **decomposition** (transfer)—decomposers break down dead organisms, releasing carbon back into the soil
- Other processes include:
  - **Fossilisation**—if animals and plants die in conditions where decomposing microorganisms are not present, the carbon in their bodies can be converted, over millions of years and significant pressure, into fossil fuels such as **peat** and **coal**
    - Aquatic organisms that die also form sediments on the sea bed

      These can go on to form other fossil fuels like **oil** and **gas**
  - **Combustion**—when fossil fuels are **burned**, the carbon locked within them combines with oxygen to form CO_2, which is released into the atmosphere

Carbon sequestration

- Carbon sequestration is the process of **capturing atmospheric CO** and **storing** it in solid or liquid forms
    - For example, trees naturally sequester carbon by absorbing CO_2 during photosynthesis and storing it in their biomass
    - Organic matter can be fossilised over millions of years to form coal, oil and natural gas, resulting in carbon being stored underground

Ecosystems as stores, sinks or sources

- Ecosystems can act as stores, sinks or sources of carbon depending on the **balance** between **inputs** and **outputs**
- Net accumulation of carbon or net release of carbon is determined by the difference between total inputs and outputs
- For example:
    - Young forest ecosystem: acts as a sink, as photosynthesis exceeds respiration, leading to net uptake of CO_2
    - Mature forest ecosystem: acts as a store, with carbon cycling between living organisms, soil and atmosphere
    - Forest destruction (fire or deforestation): acts as a source, releasing stored carbon back into the atmosphere

Human Impacts on the Carbon Cycle

Fossil fuels

- Fossil fuels like coal, oil and natural gas are stores of carbon with virtually unlimited residence times
- Fossil fuels were formed when past ecosystems acted as **carbon sinks**, trapping organic carbon over millions of years
  - They were created from ancient plants and animals that lived millions of years ago
  - Over time, their remains got buried deep underground
  - As they were buried, pressure and heat turned them into fossil fuels
- Humans burn fossil fuels for energy production
  - When burned, these fuels release heat energy
  - The heat energy can be harnessed to generate electricity, power vehicles, heat buildings and fuel industrial processes
- When burned, fossil fuels become **carbon sources**, releasing stored carbon back into the atmosphere as carbon dioxide

Agricultural systems

- Agricultural systems can act as carbon sinks or carbon sources depending on the type of agricultural and the management techniques used:
  - **Carbon sinks**: regenerative agriculture techniques like crop rotation, cover cropping, and no-till farming result in soil acting as a carbon sink
    - This is because these methods **increase** the amount of **organic matter** in the soil
  - **Carbon sources**: drainage of wetlands, monoculture farming and intensive tillage result in soil acting as a carbon source
    - This is because these methods increase the **release** of carbon from soils
- Longer-term cropping practices, such as timber production, also affect carbon cycling and storage in ecosystems
  - When forests are managed sustainably for timber production, they can act as significant carbon sinks

    - This is because they **sequester** carbon dioxide from the atmosphere through photosynthesis and **store** it in woody biomass and soil organic matter
  - However, if forests are clear-cut or managed unsustainably, they can become carbon sources
    - This is because stored carbon is **released** back into the atmosphere (when the harvested wood is burned) **quicker than it is stored** in new tree growth

Oceanic carbon dynamics

- Carbon dioxide is absorbed into oceans by **dissolving in sea water**
  - It can also **come out of the solution** and is released as a gas when conditions change (e.g. when ocean temperature increases)
- Normally, oceans act as a significant carbon sink, absorbing CO_2 from the atmosphere and helping to regulate atmospheric carbon levels
  - However, the burning of fossil fuels by humans is releasing CO_2 at a **faster rate than oceans can absorb**
    - This is leading to rising CO_2 levels in the atmosphere
  - In addition to warming ocean temperatures caused by human-induced climate change, this is reducing the ability of oceans to act as carbon sinks

Ocean acidification

- Increased concentrations of dissolved CO_2 in oceans **lowers the pH** of the sea water, leading to ocean acidification
- This is causing threats to marine organisms:
  - Small decreases in ocean pH reduce calcium carbonate deposition in mollusc shells and coral skeletons
  - This can lead to weakened shells, increased vulnerability to predators and smaller and less diverse reef structures

Reducing Human Impacts on the Carbon Cycle

Reducing Human Impacts on the Carbon Cycle

- Human activities have **significantly altered** the carbon cycle
  - This has led to increased **atmospheric carbon dioxide** levels and **climate change**
- Measures are urgently needed to reduce these impacts and restore balance to the carbon cycle
  - Example of these measure include:

1. **Low-carbon technologies**:
   - Adopting low-carbon technologies is important for reducing carbon emissions from energy production, transportation, industry and buildings (heating, cooling etc.)
     - Examples include renewable energy sources like solar, wind and hydropower, as well as more energy-efficient technologies and practices (e.g. better insulation and heatpumps)
2. **Reduction in fossil-fuel burning**:
   - Decreasing the burning of fossil fuels is an essential step in reducing carbon emissions
     - Transitioning to cleaner energy sources, such as renewables can help achieve this
3. **Using biomass as a fuel source**:
   - Promoting sustainable cultivation of bioenergy crops that does not cause deforestation—bioenergy crops absorb carbon dioxide from the atmosphere as they photosynthesise
   - Utilising bioenergy with carbon capture and storage (BECCS) technology
     - This involves producing energy from biomass
     - The carbon dioxide emissions from biomass combustion are also captured and stored underground
     - Together these processes effectively remove carbon dioxide from the atmosphere
4. **Reduction in soil disruption**:
   - Decreasing soil disruption through sustainable agricultural practices is vital for preserving soil health and maintaining the ability of soils to sequester carbon
     - Practices such as crop rotation and cover cropping can minimise soil disturbance, erosion and loss of organic matter

- Healthy soils with high organic carbon content act as carbon sinks, storing carbon and mitigating greenhouse gas emissions

5. **Reduction in deforestation**:
    - Implementing programs like the UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UNREDD)
        - This prevents deforestation and promotes sustainable forest management
6. **Carbon capture through reforestation**:
    - Reforestation involves planting trees on deforested or degraded lands to sequester carbon from the atmosphere
        - Trees absorb CO_2 during photosynthesis, storing carbon in their biomass and surrounding soils
        - Forests act as important carbon sinks
7. **Artificial sequestration**:
    - Artificial sequestration technologies capture CO_2 emissions from industrial processes and power plants, preventing them from entering the atmosphere
        - Methods include carbon capture and storage (CCS), where CO_2 is captured, transported and injected underground for long-term storage
8. **Enhancing carbon dioxide absorption by the oceans**:
    - Ocean fertilisation techniques involve adding compounds like nitrogen, phosphorus and iron to stimulate the growth of phytoplankton
        - These phytoplankton then absorb carbon dioxide through photosynthesis
    - Using methods to increase ocean upwellings
        - These upwellings bring nutrient-rich deep waters to the surface
        - This has the same effect of promoting the growth of phytoplankton and enhancing carbon dioxide absorption