Edexcel

IGCSE

Biology

CODE: (4BI1)

Unit 04

Ecology and the environment

4.14 Ecosystems

The components of ecosystems

Whatever their size, **ecosystems** usually have the same components:
■**Producers** - plants which photosynthesise to produce food
■**Consumers** - animals that eat plants or other animals
■**Decomposers** - organisms that break down dead material and help to recycle nutrients
■The physical environment - all the non-biological components of the ecosystem.

The living components of an ecosystem are called the biotic components. The non-living (physical) components are the abiotic components (compare these with **biotic** and **abiotic factors**, below).

An ecosystem contains a variety of habitats. A **habitat** is the place where an organism lives.

All the organisms of a particular species found in an ecosystem at a certain time form the population of that species. All the immature frogs (tadpoles) swimming in a pond are a **population** of tadpoles; all the water lily plants growing in the pond make up a population of water lilies.

The populations of all species (animals, plants and other organisms) found in an ecosystem at a particular time form the **community**. Figure 14.3 illustrates the main components of a pond ecosystem.

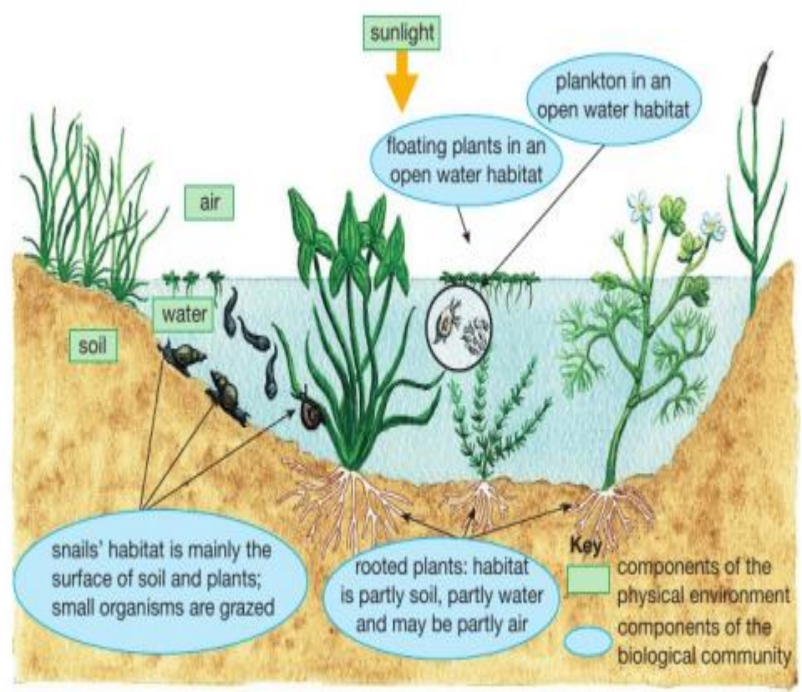


Figure 14.3 A pond ecosystem

Using quadrats to sample from a habitat

A quadrat is a sampling square used by ecologists to count a smaller representative part of a population, such as plants or animals, in a habitat, rather than counting all organisms.

Biodiversity

The amount of variation shown by species in an ecosystem is called the ecosystem's **biodiversity**. It is a combination of two measurements:
■The number of different species present (known as the species richness)
■The relative abundance of each species - their 'evenness' of numbers. Take the example of the two 'communities' shown in Table 14.1

Table 14.1 Two 'communities' of organisms.

Species	Number of individuals of each species in community 1	Number of individuals of each species in community 2
A	10	1
B	10	1
C	10	1
D	10	1
E	10	46

INTERACTIONS IN ECOSYSTEMS

The organisms in an ecosystem are continually interacting with each other and with their physical environment. Interactions include the following.

- Feeding among the organisms - the plants, animals and decomposers are continually recycling the same nutrients through the ecosystem.
- Competition among the organisms - animals compete for food, shelter, mates, nesting sites; plants compete for carbon dioxide, mineral ions, light and water.
- Interactions between organisms and the environment - plants absorb mineral ions, carbon dioxide and water from the environment; plants also give off water vapour and oxygen into the environment; animals use materials from the environment to build shelters; the temperature of the environment can affect processes occurring in the organisms; processes occurring in organisms can affect the temperature of the environment.

Biotic and abiotic factors

There are many factors that influence the numbers and distribution of organisms in an ecosystem. There are two types of factor-biotic and abiotic.

Biotic factors are biological. Many (but not all) involve feeding relationships. They include:
■availability of food and competition for food resources
■predation
■parasitism
■disease
■presence of pollinating insects
■availability of nest sites.

Abiotic factors are physical or chemical factors. They include:
■climate, such as light intensity, temperature and water availability
■hours of daylight
■soil conditions, such as clay content, nitrate level, particle size, water content and pH
■other factors specific to a particular habitat, such as salinity (salt content) in an estuary, flow rate in a river, or oxygen concentration in a lake

■pollution.

Clearly which factors affect population sizes and distribution of organisms will depend on the type of ecosystem. If you take the example of a river, some of the main abiotic factors could be:

■depth of water
■flow rate
■type of material at the bottom of the stream (stones, sand, mud etc.) concentration of minerals in the water
■PH
■oxygen concentration
■cloudiness of the water
■presence of any pollution.

Feeding relationships

The simplest way of showing feeding relationships within an ecosystem is a **food chain** (Figure 14.8).

In any food chain, the arrow (→) means 'is eaten by. In the food chain illustrated, the grass is the **producer**. It is a plant so it can photosynthesise and produce food materials. The grasshopper is the primary consumer. It is an animal which eats the producer and is also a **herbivore**. The lizard is the **secondary consumer**. It eats the **primary consumer** and is also a **carnivore**. The different stages in a food chain (producer, primary consumer and secondary consumer) are called **trophic levels**.

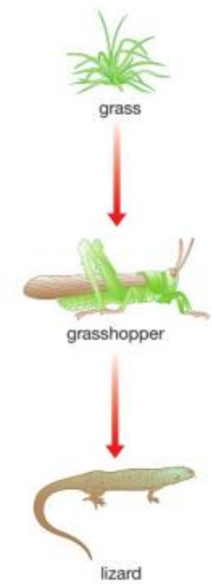


Figure 14.8 A simple food chain.

Many food chains have more than three links in them. Here are two examples of longer food chains:

filamentous algae → mayfly nymph→ caddis fly larvae → salmon

In this freshwater food chain, the extra link in the chain makes the salmon a **tertiary consumer**.

plankton → crustacean→ fish → ringed seal → polar bear

In this marine (sea) food chain, the fifth link makes the polar bear a **quaternary consumer.** Because nothing eats the polar bear, it is also called the top carnivore.

Figure 14.9 gives a clearer picture of the feeding relationships involved in a freshwater ecosystem in which salmon are the top carnivores. This is the **food web** of the salmon.

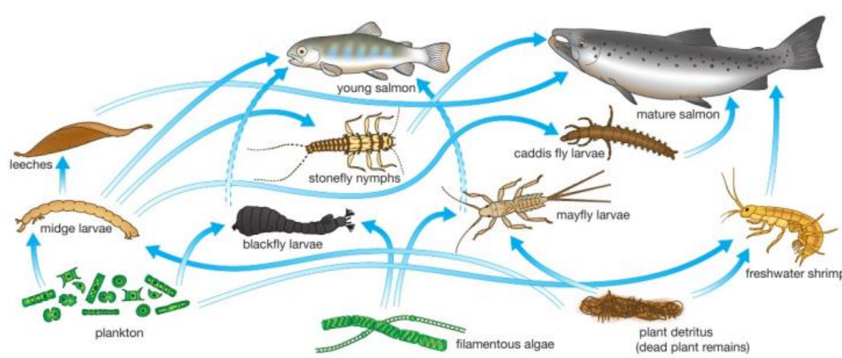


Figure 14.9 The food web of the salmon. As you can see, young salmon have a slightly different diet to mature salmon.

Ecological pyramids

Ecological pyramids are diagrams that represent the relative amounts of organisms at each trophic level in a food chain. There are two main types:

■**pyramids of numbers**, which represent the numbers of organisms in each trophic level in a food chain, irrespective of their mass

■**pyramids of biomass**, which show the total mass of the organisms in each trophic level, irrespective of their numbers. Consider these two food chains:

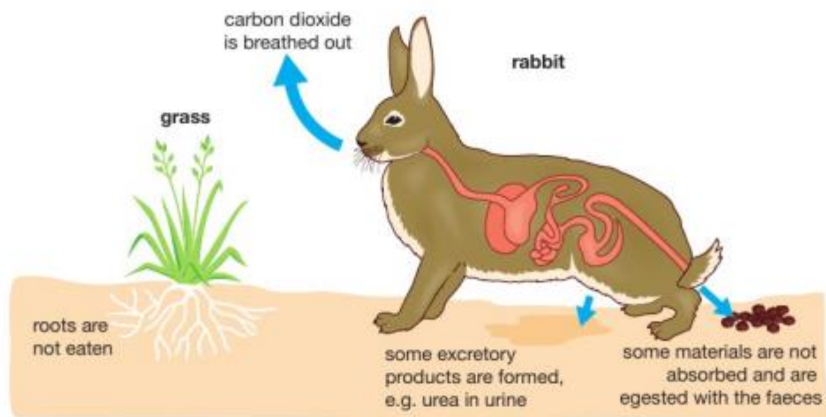
a grass → grasshopper → frog → bird
b oak tree → aphid → ladybird → bird

Figures 14.8 and 14.9 show the pyramids of numbers and biomass for these two food chains.

Why are diagrams of feeding relationships a pyramid shape

The explanation is relatively straightforward (Figure 14.11). When a rabbit eats grass, not all of the materials in the grass plant end up as rabbit! There are losses:

- some parts of the grass are not eaten (the roots for example)
- some parts are not digested and so are not absorbed - even though rabbits have a very efficient digestive system
- some of the materials absorbed form excretory products
- many of the materials are respired to release energy, with the loss of carbon dioxide and water.



▲ Figure 14.13 Not all the grass eaten by a rabbit ends up as rabbit tissue.

The flow of energy through ecosystems

This approach focuses less on individual organisms and food chains and rather more on energy transfer between trophic levels (producers, consumers and decomposers) in the whole ecosystem. There are a number of key ideas involved:

- Photosynthesis 'fixes' sunlight energy into chemicals such as glucose and starch.
- Respiration releases energy from organic compounds such as glucose.
- Almost all other biological processes (e.g. muscle contraction, growth, reproduction, excretion, active transport) use the energy released in respiration.

- If the energy released in respiration is used to produce new cells, then the energy remains 'fixed' in molecules in that organism. It can be passed on to the next trophic level through feeding.

- If the energy released in respiration is used for other processes then it will, once used, eventually escape as heat from the organism. Energy is therefore lost from food chains and webs at each trophic level.

Cycling nutrients through ecosystems

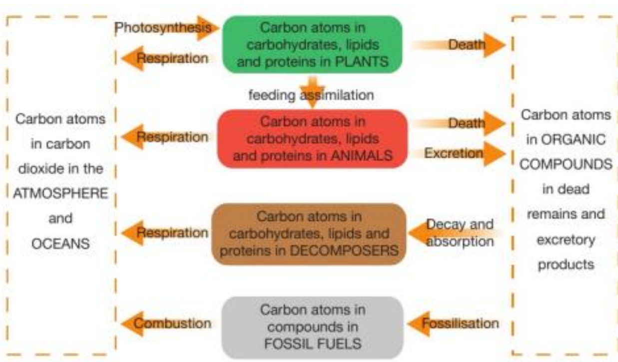
Our bodies contain chemicals that have been present before, including carbon atoms from Mahatma Gandhi and Winston Churchill. Microorganisms play a crucial role in recycling, breaking down complex organic molecules from dead animals and plants into simpler substances.

The carbon cycle

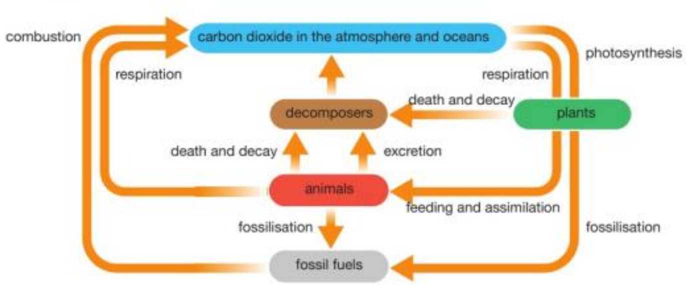
Carbon is a component of all major biological molecules. Carbohydrates, lipids, proteins, DNA, vitamins and many other molecules all contain carbon. The following processes are important in cycling carbon through ecosystems.

■Photosynthesis 'fixes' carbon atoms from carbon dioxide into organic compounds
■Feeding and assimilation pass carbon atoms already in organic compounds along food chains
■Respiration produces inorganic carbon dioxide from organic compounds (mainly carbohydrates) as they are broken down to release energy
■Fossilisation - sometimes living things do not decay fully when they die due to the conditions in the soil (decay is prevented if it is too acidic) and fossil fuels (coal, oil, natural gas and peat) are formed
■Combustion releases carbon dioxide into the atmosphere when fossil fuels are burned.

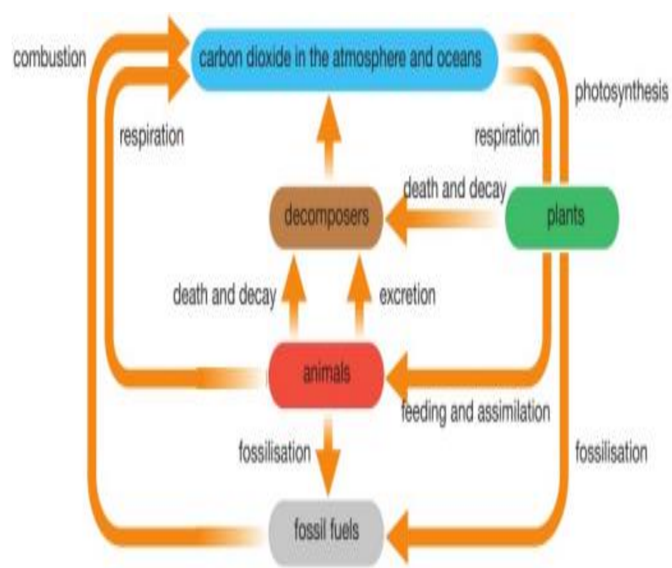
Figures 14.15 and 14.16 show the role of these processes in the carbon cycle in different ways.



▲ Figure 14.15 The main stages in the carbon cycle



▲ Figure 14.16 A typical illustration of the carbon cycle

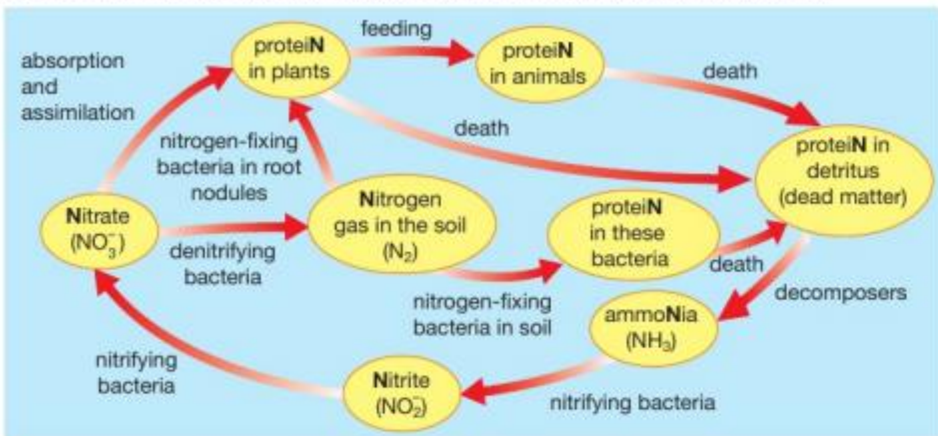


▲ Figure 14.16 A typical illustration of the carbon cycle

The nitrogen cycle

Nitrogen is a crucial element in biological compounds like proteins, amino acids, vitamins, DNA, and ATP. The nitrogen cycle involves feeding, assimilation, death, and decay. Photosynthesis and respiration fix carbon, not nitrogen. Processes involved in the nitrogen cycle include feeding and assimilation, decomposition by fungi and bacteria, nitrification, and plant roots absorbing nitrates. Other bacteria convert nitrates into nitrogen gas, reducing soil nitrate availability. Nitrogen-fixing bacteria in root nodules convert nitrogen gas into ammonia, which is converted by plants into amino acids and other nitrogen compounds.

Figure 14.18 shows the role of these processes in the nitrogen cycle.

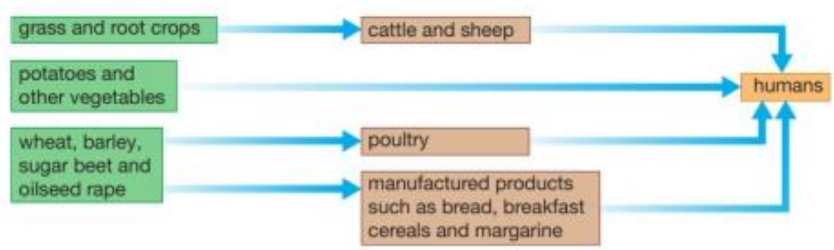


▲ Figure 14.18 The main stages in the nitrogen cycle

4.15 Human influences on the environment

Modern agriculture – producing the food we need

A modern farm is a sort of managed ecosystem. Many of the interactions are the same as in natural ecosystems. Crop plants depend on light and mineral ions from the soil as well as other factors in the environment. Stock animals (sheep, cattle, etc.) depend on crop plants for food (see Figure 15.3).



▲ Figure 15.3 A food web on a farm

Improving yields from crop plants

Glasshouses (otherwise known as 'greenhouses') and polytunnels can provide very controlled conditions for plants to grow (Figure 15.4). There are several reasons for this.

■The transparent walls of the glasshouse allow enough natural light for photosynthesis during the summer months, while additional lighting gives a 'longer day' during the winter.

■The 'greenhouse effect' doesn't just happen to the Earth, but also in greenhouses! Short wavelength infrared radiation entering the glasshouse is absorbed and re-radiated as longer wavelength infrared radiation.

■The glasshouse can be heated to raise the temperature if the outside temperature is too low.
■If heaters use fossil fuels such as gas, this produces carbon dioxide and water vapour. The carbon dioxide is a raw material of photosynthesis.

Table 15.1 Some ways the yield from crops can be improved.

Factor controlled	How it is controlled	Reason for controlling the factor
soil ions (e.g. nitrates)	adding fertilisers to the soil or growing in a hydroponic culture (Figure 15.4a)	extra mineral ions can be taken up and used to make proteins and other compounds for growth
soil structure	ploughing fields to break up compacted soil; adding manure to improve drainage and aeration of heavy, clay soils	good aeration and drainage allow better uptake of mineral ions (by active transport) and water
soil pH	adding lime (calcium salts) to acidic soils; few soils are too alkaline to need treatment	soil pH can affect crop growth as an unsuitable pH reduces uptake of mineral ions
carbon dioxide, light and heat	these cannot be controlled for field crops but in a glasshouse or polytunnel all can be altered to maximise yield of crops (Figure 15.4b); burning fuels produces heat and carbon dioxide	all may limit the rate of photosynthesis and the production of the organic substances needed for growth

Figure 15.4 (b) Many crops are grown in large tunnels made of transparent polythene, called polytunnels.

Cycling nutrients on a farm

Nitrogen and carbon cycle in nature. On a farm, nitrogen is crucial for plant proteins and livestock. When crops are sold, nitrogen in proteins is lost from the ecosystem. Farmers add fertilizer to replace lost nitrogen, but careful monitoring is necessary to ensure crop growth and yield. Excess fertilizer wastes money.

Figure 15.5 summarises the circulation of nitrogen on a farm.

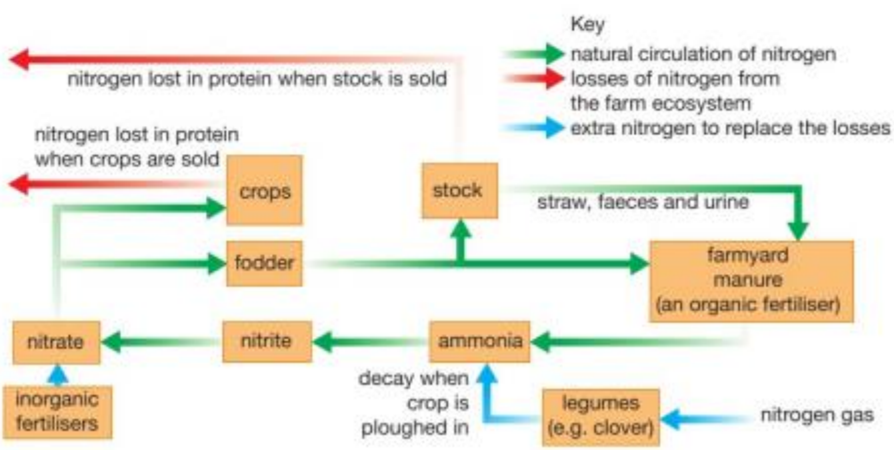


Figure 15.5 The nitrogen cycle on a farm. The effects of denitrification and lightning (see Chapter 14) have been omitted.

Fertilizers increase crop yield

Farmyard manure can help restore nitrogen to soil, but it only partially replaces lost nitrogen. Inorganic fertilisers can replace lost nitrates and minerals, but they can cause pollution and do not improve soil structure. Legumes, like clover, can replace lost nitrates by using nitrogen-fixing bacteria to convert nitrogen gas into ammonium ions. Decomposers convert this nitrogen into ammonia, which is then oxidized to nitrate for the next crop.

Pest control

Pests are organisms that reduce the yield of crop plants or stock animals. The 'yield' of a crop is the amount produced for sale. A pest can harm this in two ways:

■Lowering the amount by reducing growth, e.g. by damaging leaves and reducing photosynthesis
■Affecting the appearance or quality of a crop, making it unsuitable for sale (Figure 15.6).

Any type of organism - plants, animals, bacteria, fungi or protoctists, as well as viruses - can be a pest. Pests can be controlled in several ways. Chemicals called **pesticides** can be used to kill them, or their numbers can be reduced by using **biological control** methods.

Pesticides are named according to the type of organism they kill:

■herbicides kill plant pests (they are weedkillers)
■insecticides kill insects
■fungicides kill fungi
■molluscicides kill snails and slugs.

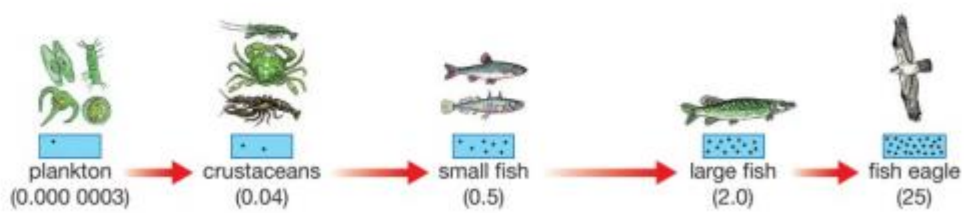
Problems with pesticides

One problem with using pesticides is that a pest may develop resistance to the chemical. This happens through natural selection (see Chapter 19). It makes the existing pesticide useless, so that another must be found. Other problems are to do with the fact that pesticides can cause environmental damage. There are several reasons for this:

■They may be slow to decompose - they are persistent in the environment
■They build up in the tissues of organisms - bioaccumulation
■They build up and become more concentrated along food chains - biomagnification
■They kill other insects that are harmless, as well as helpful species, such as bees.

An ideal pesticide should:
■control the pest effectively
■be biodegradable, so that no toxic products are left in the soil or on crops
■be specific, so that only the pest is killed
■not accumulate in organisms
■be safe to transport, store and apply be easy to apply.

DDT is very soluble in fats. When a herbivore feeds on plants that are contaminated with DDT, the insecticide is not broken down or excreted. Instead, it becomes concentrated in the fatty tissues of the animal. This is called **bioaccumulation**. When a carnivore eats the herbivore, this process is repeated, so that the insecticide builds up in concentration along the food chain. This is known as **biomagnification** (Figure 15.8).



▲ Figure 15.8 Biomagnification of DDT in a food chain

Biological control

Biological control is an alternative method to chemical pest control, involving the introduction of another organism to reduce pest numbers. For example, introducing a parasite like Encarsia can kill whiteflies in large glasshouses. However, biological control doesn't completely eliminate pests, as it aims to reduce their numbers to a level where they don't cause significant economic damage.

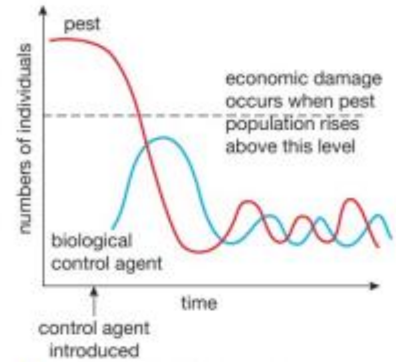


Figure 15.9 Biological control.

Fish farming

Fish farming is a growing area of animal food production, meeting the growing demand for fish as a food source over the last 60 years. Aquaculture has grown from 5% of the world's seafood in 1970 to 50% in 2016. Common farmed fish include carp, catfish, tilapia, trout, salmon, cod, bream, sea bass, and crustaceans like lobsters and prawns. About one-quarter of farmed fish is used for animal feed. Fish are kept in densely stocked tanks or enclosures, with water quality monitored and controlled. Fish farming also uses selective breeding programs to improve the quality of fish. However, environmentalists criticize fish farming for potential disease spread, antibiotic resistance, pollution, and negative effects on wild fish stocks. Carnivorous species like salmon and sea bass need to eat wild fish to produce farmed fish, and wild fish used for fishmeal are less marketable species.

AIR POLLUTION

One definition of pollution is:
'Pollution is the contamination of the environment by harmful substances that are produced by the activities of humans'.

Carbon dioxide and global warning

Carbon dioxide levels have been rising for centuries, with a nearly 30% increase in the last 100 years. This is primarily due to burning fossil fuels and deforestation of tropical rainforests, which absorb and produce carbon dioxide. The deforestation has led to less absorption of carbon dioxide.

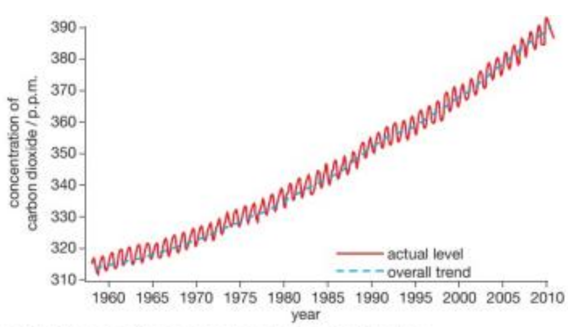


Figure 15.11 Changes in the level of carbon dioxide in the atmosphere.

The 'normal' greenhouse effect is shown in Figure 15.13..

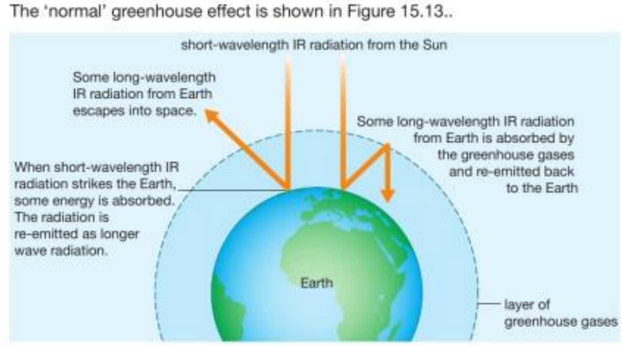


Figure 15.13 The Greenhouse effect

Methane

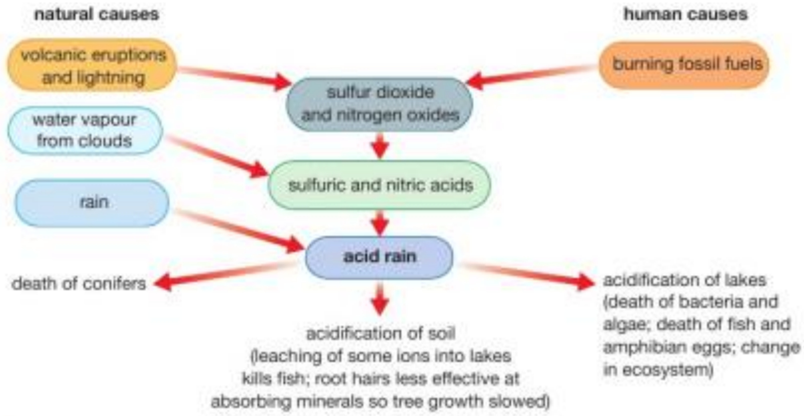
Methane (CH) is an organic gas. It is produced when microorganisms ferment larger organic molecules to release energy. The most significant sources of methane are:
■decomposition of waste buried in the ground ("'landfill sites"), by microorganisms
■fermentation by microorganisms in the rumen (stomach) of cattle and other ruminants
■fermentation by bacteria in rice fields.

Carbon dioxide

Carbon monoxide (CO) is formed when carbon-containing substances are burned in vehicles, causing colorless, odourless, and tasteless exhaust gases. Inhaled CO can cause haemoglobin to bind more strongly to CO, leading to oxygen deficiency and organ failure, potentially causing death.

Sulfur dioxide

Acid rain, formed from the combustion of fossil fuels, is a mixture of sulfuric and nitric acids, resulting from the dissolution of both sulfur dioxide and nitrogen oxides in the air, resulting in a lower pH than normal rain.



▲ Figure 15.14 The formation of acid rain and its effects on living organisms.

Deforestation

Tropical rainforests, the last great natural forests, are rapidly being destroyed by human activities, such as deforestation, due to the rapid growth of the human population. This process, primarily through slash and burn methods, contributes to global warming and climate change by removing trees that absorb carbon dioxide for photosynthesis and contributing to the atmosphere's carbon dioxide levels.

▲ Figure 15.16 Rainforest destroyed by the 'slash and burn' method.

WATER POLLUTION

Pollution of water by sewage

Two major pollutants of freshwater are sewage and minerals from fertiliser. Sewage is wet waste from houses, factories and farms. In developed countries where large-scale sewage treatment takes place, industrial and agricultural sewage is usually dealt with separately from household sewage.

If sewage is discharged untreated into waterways, it produces two major problems:

- ■ Aerobic bacteria in the water polluted by the sewage use up the dissolved oxygen in the water as they break down the organic materials. This reduction in the level of oxygen kills larger animals such as freshwater insects and fish.
- ■ Untreated sewage contains pathogenic bacteria, which are a danger to human health (see Chapter 13).

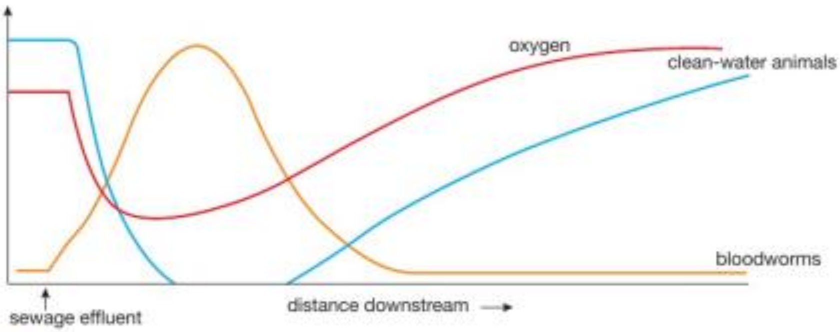


Figure 15.18 Changes in oxygen levels and types of organism living downstream from a sewage outlet into a river.

Figure 15.19 Some freshwater animals will only live in very clean water, while others can survive in very polluted areas.

Eutrophication

Eutrophication comes from a Greek word, meaning 'well-fed'. It refers to a situation where large amounts of nutrients enter a body of water, such as a river, lake or even the sea.

There are two main sources of excess minerals:

■from untreated or treated sewage

■from artificial nitrate or phosphate fertilisers.

Eutrophication is often caused using artificial fertiliser. Streams and rivers that run through agricultural land that have been treated with fertiliser can contain high concentrations of nitrate and phosphate. This is because nitrate is very soluble in water and is easily washed out of the soil by rain, a process known as **leaching**. This is less of a problem with phosphate fertiliser, but phosphate is also washed into waterways by surface run-off of water.

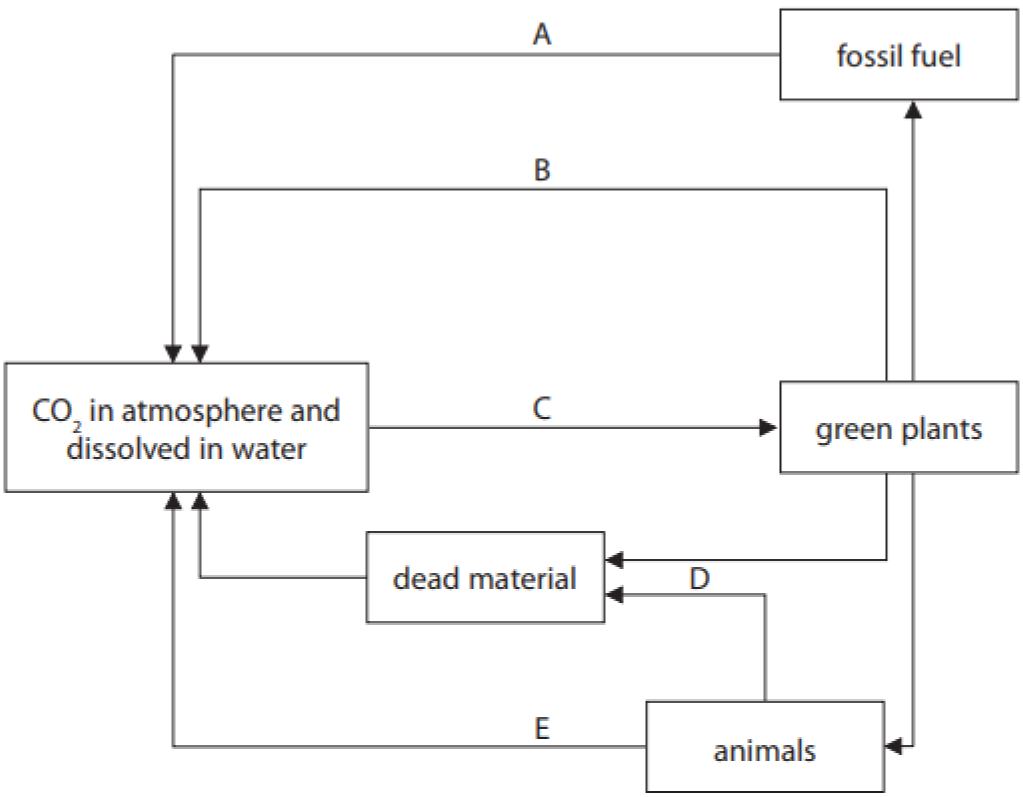
Figure 15.20 An algal bloom caused by fertiliser

The excess mineral ions stimulate the growth of all plants in the river or lake, but this is usually seen first as a rapid growth of algae, called an **algal bloom**. The algae can increase in numbers so rapidly that they form a thick scum on the surface of the water (Figure 15.20).

Revision questions

1, The passage describes the study of organisms and their ecosystems. Complete the passage by writing a suitable word in each of the spaces. . Ecology is the study of the interaction of the organisms in an ecosystem with their .... This is made up of biotic or living factors and abiotic or non-living factors. In an ecosystem a group of organisms of the same species living in one place is a .... Different groups of species living in the same place or habitat is called a .... To study the number and distribution of plants in an area, a wooden or metal frame is used. This is called a .... To compare numbers of organisms in two areas several frames need to be placed at .... places in each area. The numbers in each frame are combined and then divided by the total number of frames. This is done to calculate the .... for each area. By using several frames we improve the .... of the data and make it easier to detect any .... results.

2. The diagram shows the carbon cycle



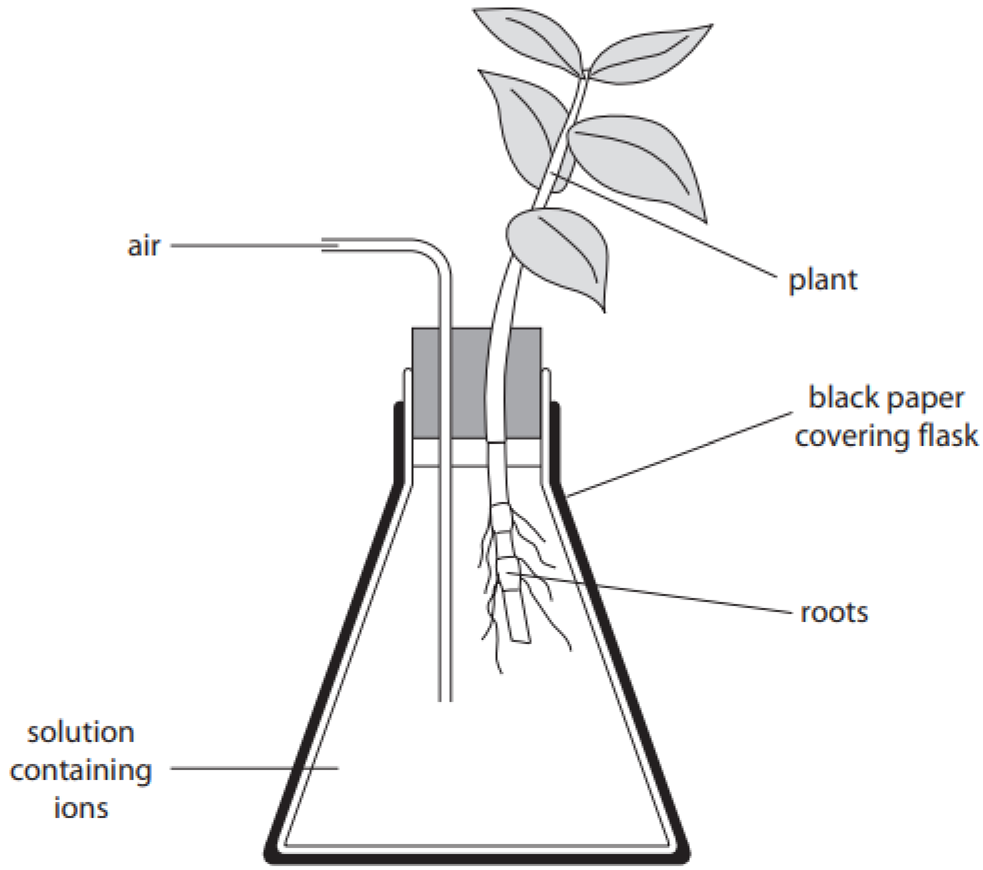
(a) (i) Identify the processes labelled A, B, C, D and E

(ii) Give the letter of the process that reduces the carbon dioxide in the atmosphere.

(b) An increase in the level of carbon dioxide in the atmosphere can lead to an enhanced greenhouse effect. Describe the possible consequences of an enhanced greenhouse effect.

(c) Suggest two ways to reduce the buildup of greenhouse gases in the atmosphere.

3. A student used this apparatus to find out if nitrate ions helped plants to grow.

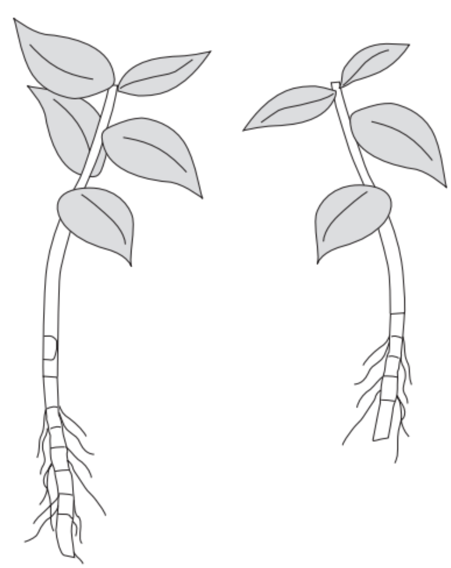


A young plant was grown in a solution that contained all the ions needed for growth. A different young plant was grown in a solution that also contained all the ions needed for growth except nitrate.

(a) (i) Suggest why the solutions have air bubbled into them

(ii) Suggest why the apparatus was covered in black paper

(b) The diagram shows the young plants after 55 days of growth



(i) Measure the length of the plants in mm and write your answers below.
plant grown in the solution containing all the ions
.... mm plant grown in the solution without nitrate ions
.... mm

(ii) Suggest how the student could make the results of the investigation more reliable

(iii) Suggest two factors, not seen in the diagram, that the student should keep the same for both plants while they are growing.

(c) Explain the consequences of fertiliser containing nitrates polluting a river.

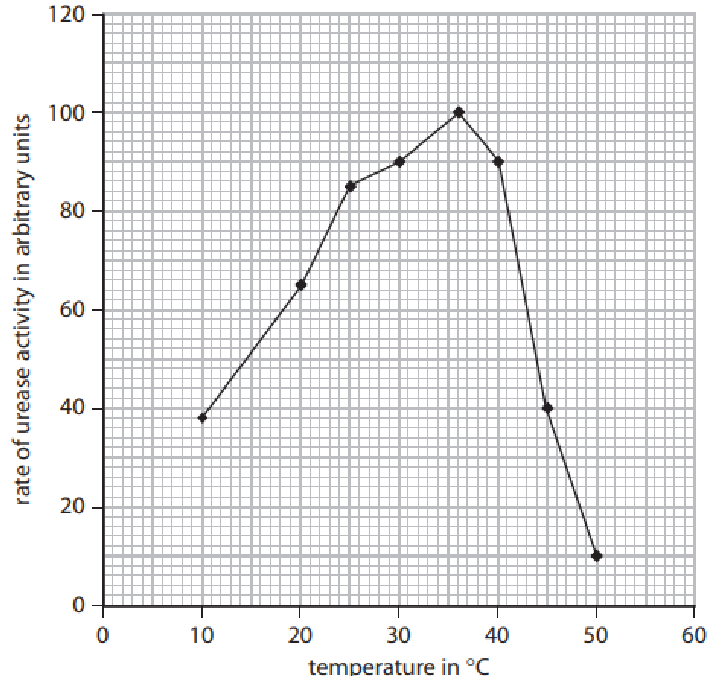
(4) 1 Nitrogen is an essential element for plant growth. Most plants can only use nitrogen in the form of nitrate ions. Only legumes that have bacteria living in their root nodules can use nitrogen from the air.

(a) (i) Explain how nitrate ions help plants to grow.

(ii) Name the type of bacteria that live in the root nodules of legumes

(b) Many animals excrete urine that contains urea. Some soil microorganisms use the enzyme urease to change urea to ammonium ions and carbon dioxide. Describe how ammonium ions can be converted to nitrate ions in the soil.

(c) The graph shows the effect of different temperatures on the rate of urease activity.



(i) Explain the change in rate of urease activity from 10°C to 36°C

(ii) Explain the change in rate of urease activity from 36°C to 50°C.

(5) (a) The diagram shows the cell wall of a bacterium. Complete the diagram by drawing and labelling the parts found inside the cell wall

(b) Decomposition by bacteria helps to release mineral ions, such as nitrates, into the soil.

(i) Explain why the rate of decomposition is affected by the pH of the soil.

(ii) Explain how nitrate ions help plants to grow

(iii) Explain how nitrate ions get into the root cells of plants.

(6) Fish produce and release nitrogenous waste.

(a) Suggest why two fish of the same size may produce different masses of nitrogenous waste.

(b) The table shows the mass of nitrogenous waste released into the environment by four different fish farms.

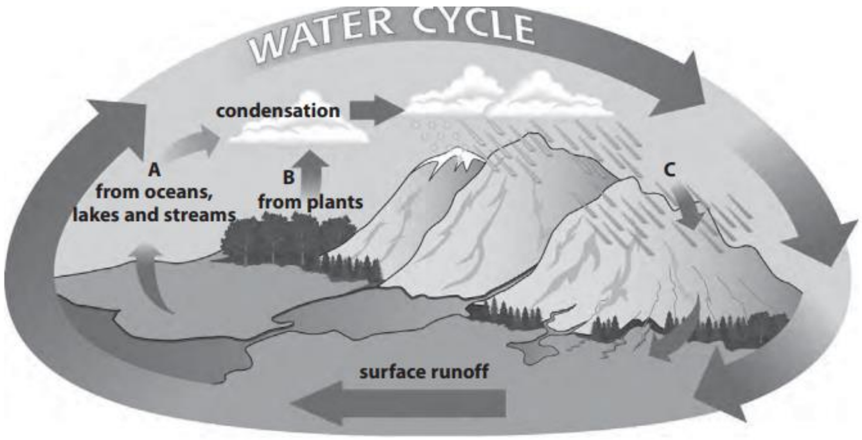
Type of fish farm	**Nitrogenous waste released in kg per 1000 kg fish produced**
salmon	48.2
halibut	67.1
cod	72.3
haddock	72.3

Calculate the mass of nitrogenous waste released into the environment when 400kg of cod fish are produced. Show your working.

(c) Nitrogenous waste released into the environment can cause eutrophication. Describe the process of eutrophication and the effects that it can have on the environment.

(d) Fish farms remove nitrogenous waste to improve the growth of fish. Another method to improve the growth of fish is vaccination. Explain how the process of vaccination improves the growth of fish

(7) The diagram shows the water cycle



(a) Name the processes A, B and C shown in the diagram.

(b) (i) Explain the possible consequences of deforestation for the water cycle

(ii) Deforestation also affects the carbon cycle. Explain these effects.

(8) When organic material in sewage, manure, silage effluents and waste milk enter a lake or river it causes pollution. The organic material is broken down by microorganisms. This process removes oxygen from the water.

The amount of oxygen removed from the water is called the Biological Oxygen Demand (BOD). The table shows data for different pollutants.

Pollutant	BOD in mg of O_2 per litre of pollutant
treated domestic sewage	20 – 60
raw domestic sewage	300 – 400
cattle manure	10000 – 20000
pig manure	20000 – 30000
silage effluent	30000 – 80000
waste milk	140000

(a) Explain which pollutant is likely to have the most severe effect on the organisms in a river.

(b) A quantity of pollutant is released into a river. The effect on the organisms will depend on the BOD value and other factors. Suggest one of these other factors.

(c) Waste milk is one of the pollutants. Name one of the biological molecules found in milk that the microorganisms could feed on.

(d) Suggest a reason for the difference between the BOD of raw domestic sewage and the BOD of treated domestic sewage.