For **Edexcel** Specifications

Advanced Subsidiary

Biology or Biology (Human)

AS Unit 3
Energy & the Environment

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Edexcel Unit 3
Energy and the Environment

Contents

3.1 Modes of Nutrition

Content

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- Basic principles

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- The adaptations of herbivores and carnivores to their diet, as illustrated by a named ruminant and a named carnivore.

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- Illustrated by *Rhizopus* and *Taenia*.

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- Illustrated by *Rhizobium* with Papilionaceae and cellulose-digesting organisms in ruminants.

AUTOTROPHIC AND HETEROTROPHIC NUTRITION

Autotrophic means 'self feeding' and it is a term applied to the nutrition of those organisms which obtain energy directly from their surroundings, taking in simple inorganic substances such as carbon dioxide, water and inorganic ions to build up complex molecules. The most important energy source for autotrophic nutrition is the sun and the most important process is **photosynthesis** by which green plants convert the sun's energy into a food resource used by all other organisms. An alternative energy source is exploited by **chemosynthetic** bacteria which use the energy produced by chemical reactions to make food. Nitrifying bacteria, for example (ref 3.4) are able to use the energy released from the oxidation of ammonium and nitrite ions to synthesise food materials and in the process release nitrates which enrich the soil.

Heterotrophic means 'other feeding' and it is applied to all organisms which obtain their energy by breaking down (digesting) materials from the bodies of other organisms. The products of digestion are simple organic molecules such as glucose and amino acids which, with inorganic ions, can be built up into more complex materials such as DNA and proteins.

HOLOZOIC NUTRITION

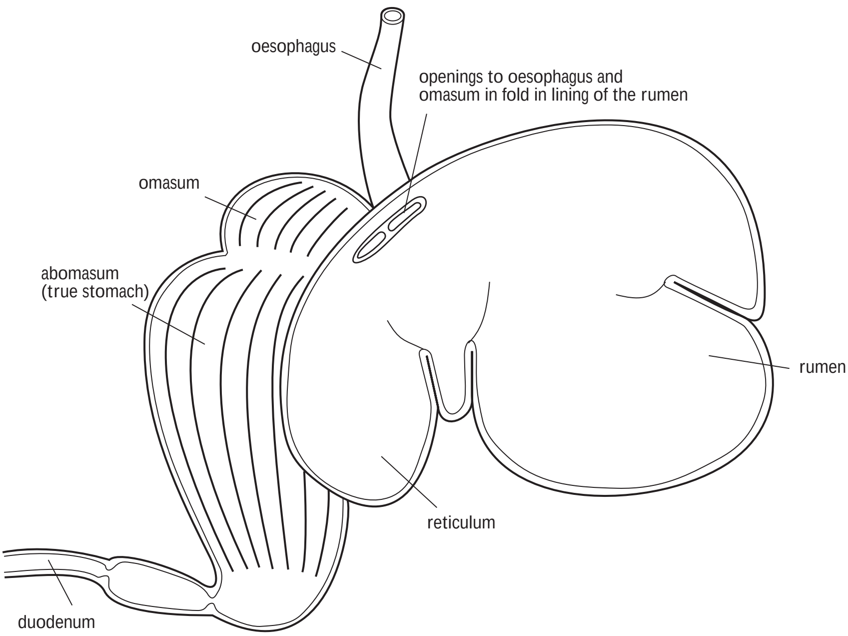
'Zoic' means 'animal like' and the term **holozoic** nutrition refers to those heterotrophs which feed 'like animals', in other words, those which engulf or swallow organic material from plant and animal sources. It includes the **herbivores** (animals which feed on plant material), **carnivores** (animals which feed on animal material), and **omnivores** (animals which obtain their food from both plant and animal sources).

Special adaptations of herbivores and carnivores to their diet

Herbivorous diet

Vegetation is relatively low in nutritional value when compared to meat. Plant cells have cellulose, and sometimes lignified, cell walls, enclosing the contents of the cells, which must be broken down before the contents can be released for digestion. Therefore vegetation requires much mastication (chewing), especially grasses, as their epidermal cell walls are hardened with silica. Therefore herbivores have many adaptations for the mastication and digestion of large volumes of plant material. Vertebrates do not produce their own cellulase enzymes, but harbour huge numbers of mutualistic microorganisms (bacteria and protoctists) which secrete cellulase enzymes. Herbivores therefore have a long complex gut in proportion to their body size, when compared to carnivores.

The complex nature of digestion and absorption in herbivores is illustrated in the **ruminants**. These include the 'cloven-hoofed' mammals such as the goats, deer, cattle and sheep.

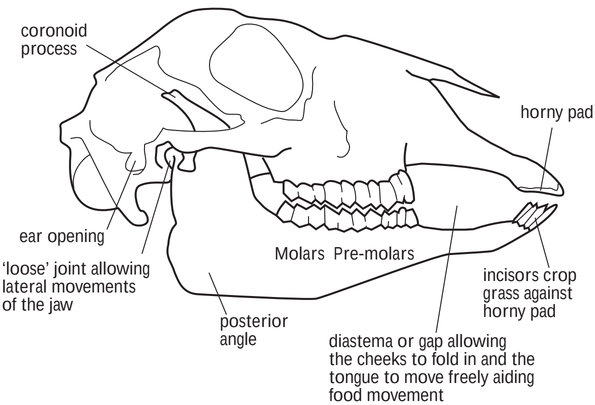


They have an elaboration of the oesophagous and the stomach into four chambers. The food is cropped and swallowed without chewing with a large volume of saliva into the chamber known as the **rumen**. The rumen contains vast quantities of mutualistic bacteria. The bacteria convert the cellulose into fatty acids which, along with lactic and other organic acids produced by anaerobic fermentation, are absorbed into the bloodstream. Large volumes of carbon dioxide and methane are also produced, and are vented off. Ciliated protoctists feed on the bacteria and are in turn digested as a source of protein. Optimum conditions for all these activities in the rumen are maintained by the production of large volumes of alkaline saliva. The food then passes into reticulum where it is stored temporarily and formed into small compact balls of cud. These are returned to the mouth where they are masticated in a process known as ‘chewing the cud’. The food is then re-swallowed into the third chamber (the omasum) where water is absorbed, and then moves into the true stomach (abomasum) where normal gastric digestion occurs. The contents of the plant cells are liberated by the breakdown of the cell walls by bacterial cellulase and then digested by normal gut enzymes in the true stomach and intestines.

Features of the skull of a herbivore

- Eye sockets at sides giving all round vision and enabling the animal to spot predators
- Incisors have a flat cutting edge and are often absent on the upper jaw (replaced by a horny pad against which vegetation is torn off)
- Canine teeth absent leaving gap (diastema) through which tongue can manipulate vegetation
- Cheek teeth (premolars and molars) are very large and have a ridged surface for grinding
- Loose jaw articulation for lateral grinding movements

Whilst carnivores hunt and kill at intervals; herbivores with their requirement for large volumes of vegetation, spend much of their time feeding.



Carnivorous diet

The carnivorous diet is mainly protein but is rich in all the necessary nutrients, and as animal cells (in meat) do not have a cellulose cell wall meat is relatively easy to digest compared to plant material. Also relatively smaller volumes have to be eaten by carnivores compared to herbivores. However, the prey must be caught (unless dead animals are scavenged) and the skull, jaws and dentition of predators are modified for cutting and tearing rather than for chewing.

Features of the skull of a carnivore

▼ Eye sockets face forwards giving binocular 3-D vision which allows the animal to judge distance when hunting.

▼ Incisors sharp and pointed for gripping prey

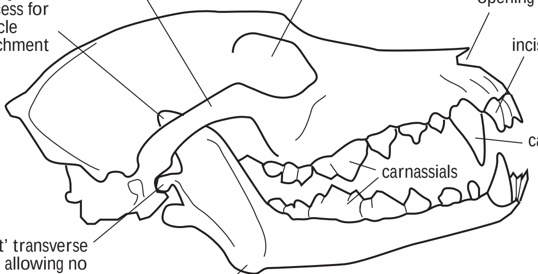
▼ Powerful canine teeth for gripping and tearing

▼ Cheek teeth adapted to sharp shearing carnassials

▼ Tight jaw articulation for scissor-like action of carnassials

▼ Central ridge on top of the skull for the attachment of muscles which power the biting action of the jaws

▼ Strong cheek bone (zygomatic arch) for strong muscle attachment



◆ CHECKPOINT SUMMARY

◆ Autotrophic nutrition is that in which the organism is capable of synthesising its organic substances from simple inorganic substances using an external energy supply

◆ In chemosynthesis the energy supply is derived from energy releasing (exothermic) inorganic chemical reactions, e.g. the oxidation of ammonium ions to nitrites by *Nitrosomonas* bacteria in the soil; and the oxidation of nitrite ions to nitrate ions by *Nitrobacter* bacteria in the soil. These two bacteria being important in the Nitrogen Cycle

◆ In photosynthesis the energy supply is derived from light which is absorbed by the photosynthetic pigments cholorophyll a and b, carotene and xanthophylls

◆ Holozoic nutrition means feeding in an 'animal-like' manner by engulfing organic material; e.g. an amoeba engulfing particles with its pseudopodia, and humans swallowing food

◆ Heterotrophic nutrition is that in which the organism requires an external source of organic substances, in addition to inorganic substances

◆ Herbivores are adapted to a diet of large amounts of difficult to digest plant material which is poor in nutrients

◆ They have a specialised grinding dentition, and long guts with mutualistic microorganisms in specialised regions digesting the tough cellulose cell walls of plant material. Ruminants soften plant materials up in specially modified 'stomachs' regurgitate it for rechewing (chewing the cud) before reswallowing

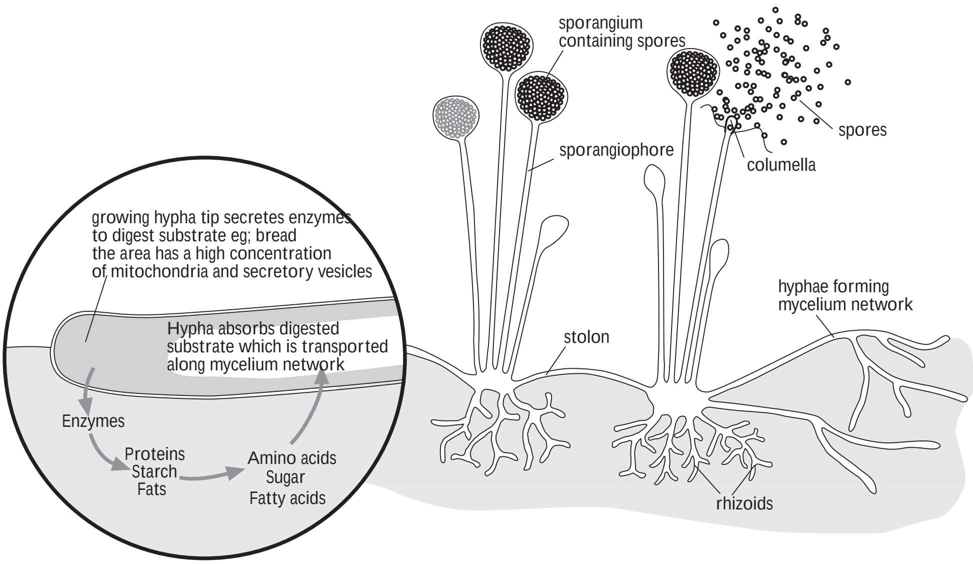
◆ Carnivores feed on other animal material which is readily digested and rich in nutrients (especially proteins)

◆ They have a sharp piercing and slicing dentition to kill the prey and tear off the muscle, tendons and bones. The food is not chewed, and the gut is relatively short and simple.

SAPROBIONTIC AND PARASITIC NUTRITION

Saprobiontic organisms are heterotrophs which live and feed on dead and decaying organic material. They include many fungi and bacteria and are referred to as **decomposers**, having a vital role in the recycling of nutrients. This mode of nutrition is well illustrated by the mould fungus *Rhizopus* which is commonly seen growing as a hairy covering on bread. The fungal threads (**hyphae**) which make up the body (**mycelium**) of the organism are white; the greyish appearance is caused by thousands of spore cases (**sporangia**) which are on top of 'stalks' growing vertically up from the main fungal mass (**mycelium**).

Rhizopus feeds by secreting digestive enzymes, principally amylase, onto the food material, and absorbing back the products of digestion. This process, called **extracellular digestion** relies on the presence of sufficient moisture, both for the hydrolysis of food, and for the digested products to be dissolved prior to their uptake by the feeding hyphae. The hyphae of the mycelium have a huge surface area to volume ratio which facilitates extracellular digestion and absorption.



Parasitic nutrition

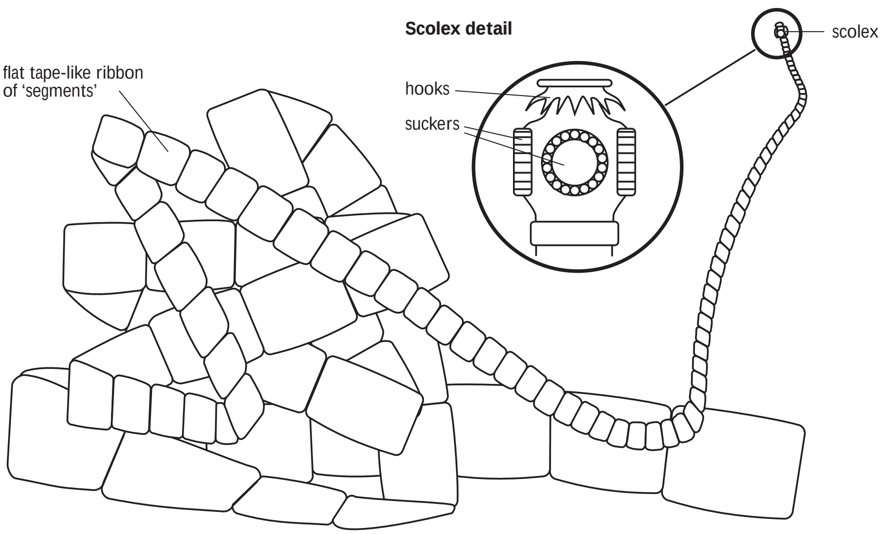
A parasite is an organism which lives on or in, and obtains its food from, the living body of another organism of a different species (the host); to the benefit of itself and the harm of the host. Parasites may feed externally (**ectoparasites**) on plants (e.g. aphids) or animals (e.g. fleas); or they may enter the body to feed internally (**endoparasites**) e.g *Phytophthora infestans* (the potato blight fungus) and *Taenia* (the tapeworm). The endoparasitic mode of nutrition necessitates various adaptations to body form and physiology which are well illustrated by *Taenia*.

Taenia solium (pork tapeworm) lives in the small intestine of its human host and benefits from a rich and constant supply of ready-digested foods which it simply absorbs across its body surface. Being flattened in form, it has a very large surface area to volume ratio for this purpose. Being in such constant optimum conditions *Taenia* shows a reduction in sense organs, powers of locomotion, and it has no gut of its own.

The small intestine is, however, a very hostile environment for a living parasite. Special adaptations are needed to cope with constant peristaltic movements, a lack of oxygen, and digestive fluids which would break down unprotected animal tissues. *Taenia* is protected by a resistant cuticle over its body surface and attaches to the gut wall by means of hooks and suckers. It respires anaerobically.

Endoparasites have a major problem ensuring that offspring reach new hosts, and this is overcome by huge powers of reproduction, and complex life cycles, often involving more than one host.

Taenia solium has a complex life cycle involving a **secondary host**, the pig, in which its larval stages develop.



MUTUALISTIC NUTRITION

Parasitism is an association between two organisms whereby one, the parasite, gains from the association and the other, the host, is harmed to a greater or lesser degree. A mutualistic association between two organisms is one which benefits both. The two examples described below both involve bacteria, one is a nitrogen source provider with a plant for a partner, the other a cellulose digester in partnership with an animal.

Rhizobium, a nitrogen fixer and the Papilionaceae

The Papilionaceae are a family of pod bearing plants including peas and beans and clover. They have an advantage over other plants because they form mutualistic associations with bacterial colonies of the genus *Rhizobium* capable of 'fixing' atmospheric nitrogen into compounds which can be used by the plant to make protein (ref. 3.4). Freely moving Rhizobia enter the relatively unprotected root hair cells of Papilionaceae plants and, once inside, they become enlarged into a form called **bacteroids**. Bacteroids multiply rapidly and affect their host cells in two ways. They cause the cell to produce tiny cellulose tubes called **infection threads** through which they can migrate to the deeper tissues of the root cortex and they secrete chemicals (cytokinins) which induce rapid multiplication of the root cells. The result is a swollen tumour or **root nodule** containing millions of *Rhizobia*.

Rhizobium possesses the enzyme **nitrogenase** which catalyses the conversion of nitrogen gas and hydrogen ions (from bacterial respiration) to ammonia (NH_3). Ammonia can be used directly by the plant, in combination with glutamate to make the amino acid glutamine from which other amino acids can be manufactured. The bacterial cells benefit from the association by having a ready supply of water, and carbohydrates from the plant's photosynthesis, and a degree of protection from competition.

Cellulose digesting organisms in ruminants

These have been referred to above in the account of digestion in ruminants. They are anaerobic bacteria which secrete cellulase enzymes to digest cellulose to glucose, which is absorbed by both the bacteria and the host, or fermented to fatty acids which are in fact the main source of energy for the host ruminant. It is this fermentation that produces the large volumes of carbon dioxide and methane, which on a world scale are significant 'greenhouse' gases. The bacteria can also synthesise amino acids from ammonium ions present in the rumen (urea may be added artificially to the diet of dairy cows to encourage this).

◆ CHECKPOINT SUMMARY

- Saprobionts (Bacteria and Fungi) physically live on dead or decaying organic matter from which they gain their nutrients. The organism secretes extracellular digestive enzymes onto the organic matter and absorbs the soluble end products of digestion by diffusion. Saprobionts are vital in the recycling of matter e.g. carbon and nitrogen cycles
- A parasite is an organism that lives on or in another organism of a different species to its own benefit and the harm of the host
- Thus parasitic nutrition is that carried out by a parasite. Parasites can absorb readily digested material (tapeworm in the gut), bite and feed on blood and fluids of the host (hookworm in the gut), or feed on nutrients in body fluids and cells (malarial parasite in the blood)
- *Rhizopus* produces a mass of filaments (hyphae) collectively known as a mycelium over and through the dead organic matter. This mycelium has a huge surface area to volume ratio over which it carries out extracellular digestion and absorption of the soluble end products
- *Taenia* (tapeworm) lives in the gut of vertebrates from which it absorbs the ready digested nutrients. Its long flat tape-like body shape provides a large surface area over which to absorb the nutrients, and has a large surface area to volume ratio for their diffusion to all parts of the body
- Mutualistic nutrition involves two organisms from different species gaining a mutual benefit in nutrition from their close association
- *Rhizobium* is a bacterium mutualistic in the root nodules of plants of the Papilionaceae family (legumes e.g. beans, peas, gorse, clover etc.)
- *Rhizobium* gains organic compounds from the plant, and the plant gains nitrates from Rhizobium
- Microorganisms in the gut of ruminants secrete cellulase enzymes for the digestion of cellulose in the plant material. This liberates the contents for further digestion by the ruminant, and the microorganisms benefit from this.

3.2 Ecosystems

Content

- Biosphere, ecosystem, habitat.
- Producers, consumers and decomposers
- Trophic levels, food chains and food webs.

The Biosphere

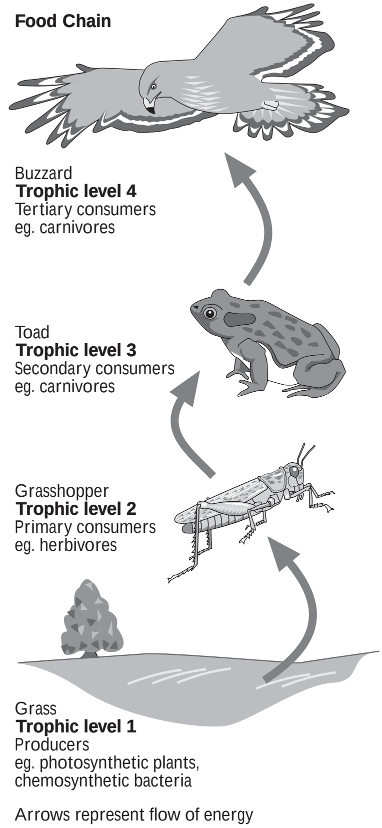
The **biosphere** is the name given to that section of the planet which can be inhabited by living organisms. It extends from the upper reaches of the atmosphere to the depths of the oceans, and includes regions as different as the polar ice caps and hot volcanic springs, although these extreme environments can only be exploited by a few specialised life forms. Most organisms require more moderate conditions and exist in mixed communities within defined, and more or less self-contained, sections of the biosphere referred to as **ecosystems**. Terrestrial ecosystems are characterised by a particular type of vegetation, for example, grassland or coniferous forest. Aquatic ecosystems are defined by the type of water: fresh, salty, still or running. An ecosystem consists of three interrelated components: **biotic** (the community of living organisms), **climatic** (temperature, rainfall light etc.) and **edaphic** (soil or water composition).

Each of these components is dependent on the other. In a forest for example, the trees depend on the soil for minerals, but the soil is made stable and fertile in return by the plant roots and decomposing parts of the trees, e.g. leaves. The trees also depend on the climate for light and water, but rain clouds are made up of water vapour, some of which has been transpired from the tree leaves, and large forests have a significant effect on rain fall.

Each living organism has its own **habitat** within the ecosystem. A habitat must provide three essential things which the organism needs to survive. Firstly, it must supply food through all seasons of the year. It must also offer protection from extremes of climate and from other organisms. Finally, it must provide a place to breed, for example, nesting sites and materials for nest building.

For an earthworm or a dandelion all these needs can be supplied by a small area of garden soil. Larger animals require a much greater portion of their ecosystem. Elephants travel many miles to satisfy their needs for food and water, and eagles require large hunting areas with isolated and protected nesting sites. It is small wonder that the creatures with the largest habitat requirements are under the greatest threat from expanding human populations (ref. 3.6).

The term **community** refers to the entire set of organisms which coexist within a particular ecosystem. The total number of individuals of any particular species within that community is termed a **population**, so communities are composed of many different populations. A typical ecosystem such as a pond or forest consists of populations of producers, consumers and decomposers.The **producers** are the organisms which manufacture food from inorganic substances. They are autotrophic organisms (ref 3.1), by far the most important of which are photosynthetic green plants. All other organisms which make up the community are **consumers**, and rely on producers, directly or indirectly, for their food. One group of consumers is given a separate name related to their role in the ecosystem. They are the **decomposers** comprising microorganisms, mainly bacteria and fungi, which live and feed saprobiontically on dead organic materials, and release simple reusable substances such as inorganic ions back to the environment. They are particularly important to any ecosystem because they ensure that inorganic nutrients are recycled.



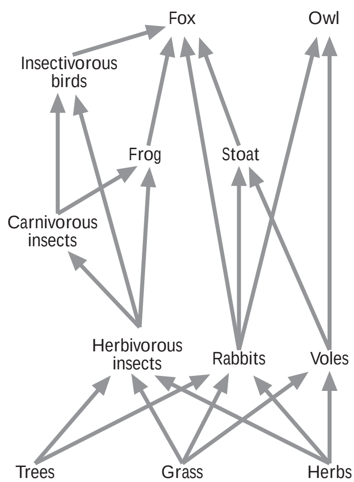
Trophic levels, food chains and food webs

The green plants which constitute the base of most ecosystems convert a small part of the sun's energy, through the process of photosynthesis into a stored chemical form. This is the direct origin of food for herbivores and is ultimately the only source of energy for every other living organism. The sequence of organisms from producers through the chain of consumers is known as a **food chain**.

One way of determining the sequence of events would be simply to observe organisms feeding in captivity, for example pond organisms could be kept in an aquarium, but this method is not only time consuming, it is open to misinterpretation, since the same results may not apply in a natural ecosystem. Some food chains have been partially established by the analysis of gut contents, but this is a method which is only suitable for those organisms which have hard parts like a shell or exoskeleton which are not digested. More sophisticated methods of analysis include the labelling of plant food with radioactive isotopes like P^{32} which can be sprayed onto leaves in the form of phosphate. The organisms in the suspected food chain can then be tested for the presence and relative amount of P^{32} in their body.

Food chains always start with a **producer**. Herbivores are the **primary consumers** and subsequent organisms higher up the food chain form **secondary consumers**, **tertiary consumers** and so on. These feeding levels are called **trophic levels,** with the producers making up the first trophic level, and herbivores the second trophic level etc. It is very rare to find a chain of more than five or six organisms because the amount of available energy is greatly reduced at each trophic level (see section 3.3)

In natural ecosystems, food chains present much too simplified versions of feeding relationships. The buzzard, for example, does not depend exclusively on rabbits for its nutritional needs, but will eat other organisms as well such as voles, mice and amphibia. A very complex network of interrelated food chains exists which is best illustrated by a **food web**. Since a food web of this kind is based on green plants it is called a **grazing food web**. Grazing food webs omit some very important organisms, namely decomposers which exist within a food web of their own (the **detritus food web**). Another group of organisms which are also present in communities and which cut across all the trophic levels of a grazing food web are the parasites. A complete picture of feeding relationships should therefore be composed of three interlinking food webs, the grazing food web, the detritus food web and the **parasitic food web**.



3.3
Energy Flow

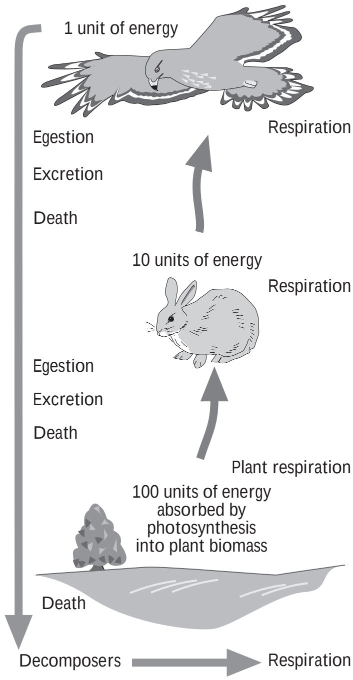
Content

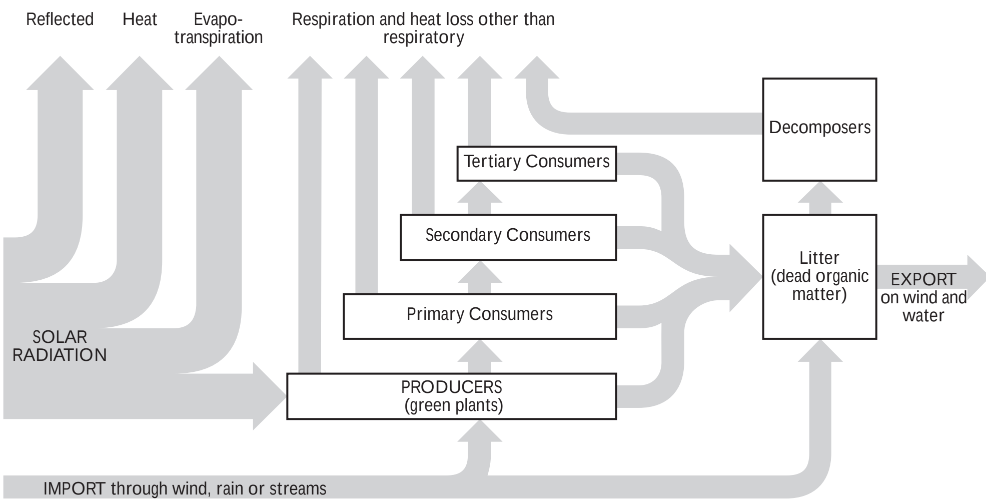
- The conversion of carbon dioxide and water to glucose and oxygen, using energy from sunlight in photosynthesis and the absorption of light energy by chlorophyll.
- The role of producers, consumers and decomposers in food chains and food webs.
- The quantitative analysis of food chains using pyramids of numbers, biomass and energy;
- The transfer of energy through food chains and food webs and why energy is lost between trophic levels.
- Productivity, gross primary production and net primary production.

Photosynthesis, producers and consumers

As you have seen in 3.2, all of the food materials generated within an ecosystem are manufactured by producers, autotrophic organisms which can produce organic compounds from simple inorganic substances such as carbon dioxide and water using an external source of energy. Green plants are the most important producers. Light energy is absorbed by chlorophyll, and converted to chemical energy within the chemical bonds of organic compounds e.g. glucose in the process of photosynthesis. This organic material and its energy is exploited by other organisms, the consumers. Consumers are **heterotrophic** organisms which cannot produce their own food from simple inorganic sources using external sources of energy, and must obtain a supply of ready-synthesised organic compounds from other organisms.

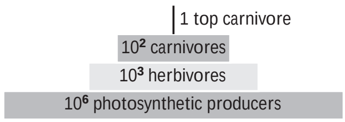
The inorganic materials are continually recycled, but ultimately all the energy originally absorbed by the chlorophyll in photosynthesis is lost as heat. Energy is therefore described as flowing through an ecosystem, and depends on continual input from the sun.

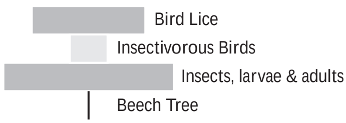




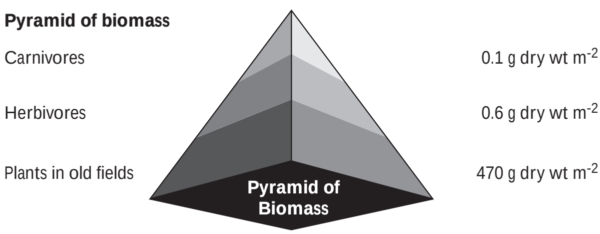
Pyramids of numbers, biomass and energy

The organic materials containing chemical energy are passed from organism to organism through food chains and webs. These materials are used to produce the biomass of the organisms in the food chains and webs, and as a source of energy for all their activities. As the result of inefficiencies of energy conversion and its use, a certain amount of energy is lost as heat back to the environment. If the different consumers in an ecosystem are arranged in their feeding sequence, from producers to herbivores to carnivores they form ecological pyramids. Generally the organisms in grazing food webs form a **pyramid of numbers** when arranged in their trophic levels. Predators, for example, tend to be larger than the animals they eat and as a result of the inefficiencies described above, they consume many of them during a single life span. It follows that there must be more prey than predators.





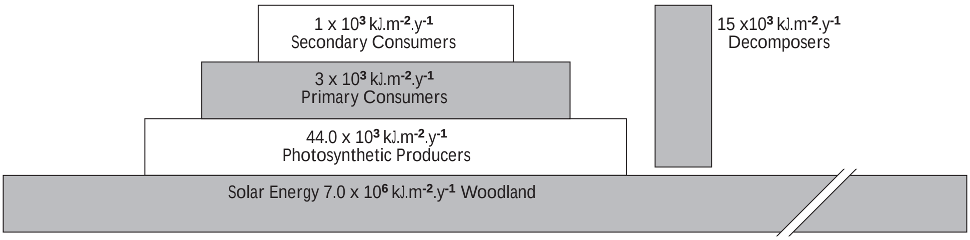
Obvious exceptions to this general principle are where the producers, being trees or large plants are larger and fewer in numbers than the herbivores (primary consumers) they support. A more accurate representation is a **pyramid of biomass** where the producers form the largest mass and the top carnivores, the smallest. In this pyramid, biomass is taken to mean the total amount of organic matter at each trophic level measured in grams dry mass per m^2.



◆ CHECKPOINT SUMMARY

- The biosphere is that zone of the earth and its atmosphere that supports life
- An ecosystem is a more or less well defined region in which three components: biotic (living organisms), climatic, and edaphic (geology, soil and water) interact e.g. a fresh water pond
- Habitat means 'home' or 'address' within an ecosystem. The three primary 'drives' - to feed, to protect, to reproduce must be satisfied by the habitat e.g. leaf litter in a woodland
- These definitions are fairly arbitrary and artificial with many overlaps and anomalies
- They are only useful if they clarify discussions of problems in ecology, and too much emphasis should not be put on their definition for its own sake
- Producers 'produce' the organic matter on which all life depends. Virtually all producers are photosynthetic, converting light energy from the sun into the stable chemical energy of organic compounds
- Consumers 'consume' producers and each other to obtain a supply of ready-made organic material
- Feeding relationships can be considered as food chains and webs with organisms at different feeding or trophic levels, although organisms can feed at more than one level
- Typically there is a maximum of four trophic levels in a food chain as a result of the losses of material and energy at each level.

Pyramids of biomass give a quantitative assessment of the ways in which food is passed through the trophic levels. However, biomass measurements change over the course of a year with the seasons; leaf fall in autumn, for example, produces disproportionate amounts of dead matter and alters the balance of organisms. More importantly, biomass is not directly comparable between different feeding groups, e.g. one gram of cows' milk is not comparable with one gram of grass. The best units of measurement are energy units (kJ per m^2 per year) and on this basis, a **pyramid of energy** can be constructed which accurately compares the energy transfer between each trophic level, including the initial transfer of sunlight by the producers, but the figures for this are difficult to obtain and process.



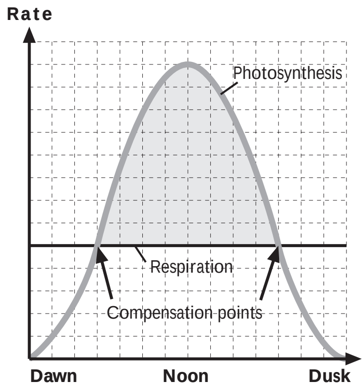
◆ CHECKPOINT SUMMARY

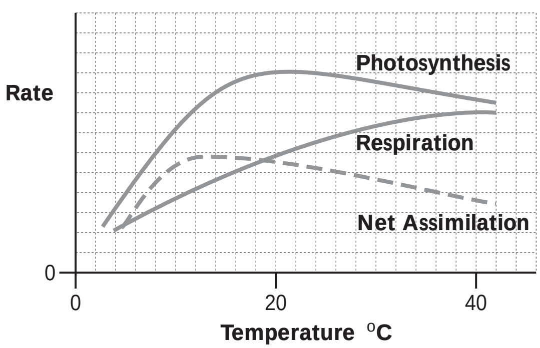
- Carbon dioxide and water are converted to glucose and oxygen, using energy from sunlight in photosynthesis and light energy is absorbed by chlorophyll and its accessory pigments
- In addition to producers and consumers, decomposers have a key role in the recycling of matter e.g. carbon and nitrogen cycles
- Decomposers reduce dead organic matter to simple inorganic compounds, e.g. carbon dioxide, and ammonium ions, which can be reabsorbed by producers and progress through food webs and chains again
- Food chains can be described quantitatively by means of pyramids of numbers, biomass and energy
- Pyramids of number may be inverted in certain cases e.g. thousands of aphids (greenfly) feeding on a single bean plant
- Pyramids of biomass avoid this anomaly and are always the right shape, at least if the biomass is calculated as dry biomass
- Pyramids of energy are similarly always the right shape
- The efficiency of energy transfer between trophic levels is typically less than 10% due to losses in conversion
- Photosynthetic producers only trap a small fraction of the available energy of sunlight, inefficiencies of digestion and absorption mean that most organic matter is not assimilated by consumers
- Energy losses as heat as a result of the inefficiencies of cell respiration also occur.

Productivity

The transfer of food energy from one organism to another is always wasteful. Each organism has its own energy requirements and releases heat to the environment as a result of its metabolism, especially movement. Other losses occur in the faeces and through nitrogenous excretion. Note that energy conversions work in one direction only. The sun's energy is not recycled in ecosystems, but flows through the food webs in chemical form and out of them as heat.

The efficiency with which the plants of an ecosystem convert light into food energy (**productivity**) can be estimated by collecting samples of plant material over a period of a year from selected sites. The material is weighed, dried to constant mass, and then burned in a calorimeter to give a measure of its energy content. In this way it is possible to estimate the amount of energy produced in a measured area of land over the period of a year. This is referred to as **gross primary production** and is measured in $kJ.m^{-2}yr^{-1}$. Plants use some of this energy for their own growth purposes. Therefore the quantity available to consumers is called the **net primary production**.





◆ CHECKPOINT SUMMARY

- ◆ Productivity refers to the rate at which energy can be stored in organic substances by producers and has two sub-divisions
- ◆ Gross primary production refers to the rate at which energy is stored by plants
- ◆ Net primary production refers to that which is in excess of the plants own respiratory requirements and is potentially available to the next trophic level.

3.4 Recycling of Nutrients

Content

- The water cycle.
- The role of microorganisms, carbon sinks and carbonates in the carbon cycle.
- The stages in the nitrogen cycle and the role of microorganisms in the cycle as illustrated by decomposers, nitrifying bacteria (*Nitrosomonas, Nitrobacter*), nitrogen-fixing bacteria (*Rhizobium, Azotobacter*), and denitrifying bacteria (*Pseudomonas and Thiobacillus*).
- The disruption of the carbon and nitrogen cycles by human activities.

Bio-geological Cycles

Whilst energy flows through an ecosystem in one direction only and its supply must continually be renewed by the sun, the elements which make up the bodies of living organisms are fixed in quantity and are recycled and reused. When organisms die, their component molecules and ions are released back to the environment through the activity of decomposers. They may pass into the atmosphere as gases, enter the earth's oceans as dissolved minerals or become locked up in geological formations. Later, after millions of years or just a day or two, they may be taken up again by producers and made once more into components of a living organism.

The water cycle

97% of the earth's water is contained within the oceans, a varying proportion of which is frozen solid at the poles. The quantity available to living organisms in terrestrial environments depends upon the rate at which water leaves the oceans and returns to it. Water evaporates from the oceans and the water vapour eventually condenses as clouds and falls as rain. That which falls on land will run off the surface, and soak down to form the 'water table', some becoming trapped in deep lying porous rocks as underground reservoirs or 'aquifers'. Water also drains away into streams, rivers, lakes, and most eventually returns to the oceans. Vegetation, especially forests, plays an important part in returning water from the soil to the atmosphere as water vapour as a result of their transpiration. Forests have a significant effect on climate, and deforestation in hot dry climates and on poor soils can lead to the development of deserts. Water dissolves inorganic substances from the rocks and soils that it passes through, and these are the cause of the 'saltiness of the oceans' as only pure water evaporates, leaving the inorganic substances behind in solution.

The Carbon Cycle

The carbon cycle revolves around the balance between photosynthesis and respiration. The simple equations of each of these processes show the relationship between them:

Photosynthesis

$$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Respiration

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

As can be seen, photosynthesis converts carbon dioxide (CO_2) into organic compounds such as glucose ($C_6H_{12}O_6$); and respiration breaks these down, releasing carbon dioxide into the environment. Respiration can be of living plants and animals, or of decomposers.

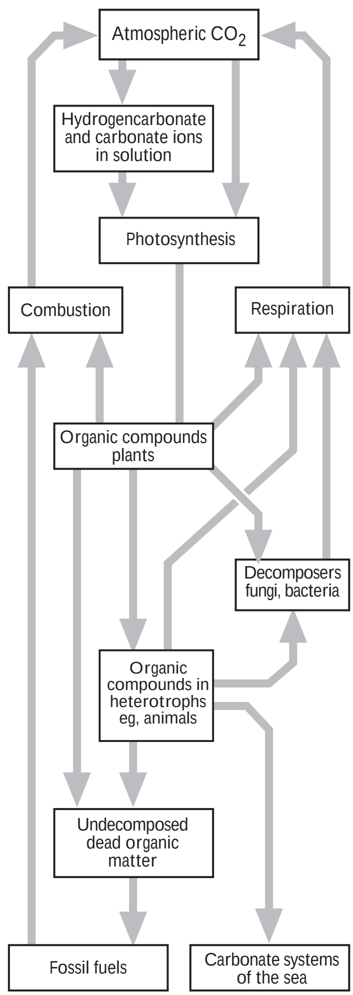
Not all of the carbon circulates freely in the cycle, much becomes trapped in '**carbon sinks**' where it is removed for varying amounts of time from free circulation around the carbon cycle. The length of time spent in such 'carbon sinks' can vary considerably.

Some of the carbon taken in by marine animals in their food becomes incorporated into calcium carbonate, for example, in the shells of molluscs or the rocky substance of corals, and over an immense span of time may be locked up in geological formations of limestone and chalk. Calcium carbonate may also be formed chemically from solution. This geological reservoir of carbonate may, over the years, be eroded and washed back into rivers and oceans where, once more, the carbon, now in the form of carbonate ions, may be taken up by producer organisms.

Many trees are long lived and their organic compounds represent a 'carbon sink' which could endure for several hundred years. Forests are to be planted specifically to act as 'carbon sinks' in an attempt to remove excess carbon dioxide released into the air by combustion of carbon containing fossil fuels.

Much of the biomass of dead organisms does not decompose completely, but accumulates over millions of years as coal, oil and gas.

Carbon cycle



Human influences on the carbon cycle

The main effect of human activities on the carbon cycle is in the release of carbon dioxide into the atmosphere as a result of the combustion of fossil fuels such as coal, oil, and petroleum products in power stations and in cars. It took many millions of years for this carbon dioxide to be trapped by photosynthesis into organic compounds, which then slowly formed the deposits of coal and oil (carbon sinks), thus effectively removing it from the carbon cycle. However, the combustion of these fuels since the early 1900s (now at a rate of about 6×10^9 tonnes per year), releases carbon dioxide into the atmosphere at a rate faster than that at which it can be reabsorbed into the carbon cycle. One third of this annual production is absorbed by the world's forests through the process of photosynthesis, one third is absorbed somewhere (unknown) in the cycle, and one third increases the carbon dioxide concentration in the atmosphere. Pure air contains about 0.04 % carbon dioxide and it is calculated that this represents an increase of about 35% on that existing in the early 1900s.

Carbon dioxide is described as a **greenhouse gas** (see section 3.6) contributing to a layer in the upper atmosphere which traps some of the sun's radiant heat. Incoming radiant energy from the sun is of a wavelength short enough for about 70% of it to penetrate the greenhouse layer. Some of this energy serves to warm the earth's surface. Radiant energy is emitted back from the earth's surface in the form of a longer wavelength which does not pass so readily through the greenhouse layer but becomes trapped and redirected back to earth. The thicker the layer of greenhouse gases, the more the earth will warm up, an effect called **global warming**. Scientific models and predictions of the effect of increasing amounts of carbon dioxide in the atmosphere are notoriously unreliable in predicting the rate of global warming, but there is no doubt that the arguments revolve around 'when' and not 'if'.

◆ CHECKPOINT SUMMARY

- The geological water cycle involves the evaporation of water into the atmosphere and its precipitation from the atmosphere (rain, snow, hail etc)
- Water is essential for life and living organisms exploit various water supplies. Transpiring plants play a major part in drawing water from the soil and evaporating it to the air
- Much water drains away to deep lying deposits of porous rocks (aquifers) where it is essentially removed from the water cycle
- The carbon cycle involves the cycling of carbon from carbon dioxide in the atmosphere (or hydrogen carbonate ions in aquatic ecosystems) to carbon containing organic compounds and back again
- Photosynthesis converts carbon dioxide into organic materials which are exploited by consumers (and decomposers) and move through food chains and webs
- Respiration of living organisms (including that of decomposers) releases carbon dioxide back to the atmosphere
- Long living organisms e.g. trees act as temporary carbon sinks which remove carbon from the cycle for a period of time. More permanent sinks are represented by fossil fuels (coal and oil), and carbonates of shelled organisms which form chalk and limestone deposits
- Microorganisms acting as decomposers play a major role in releasing carbon back into the cycle as carbon dioxide
- Man now has a considerable effect on the carbon cycle by the combustion of fossil fuels (coal and oil) which releases carbon dioxide from these sinks in a very short time.

The Nitrogen Cycle

Nitrogen is a vital component of protein, ATP and nucleic acids in living organisms, making up about 3% of the total body mass of humans. Nitrogen gas composes 80% of the atmosphere but only a select group of microorganisms called nitrogen fixers can actually use this source. Plants take up nitrogen in the form of nitrates and ammonium ions from the soil, combining them with carbohydrate molecules synthesised by their leaves to make the protein, nucleic acids and other compounds that they need. Most other organisms take in nitrogen in this organic form through the food chain.

The principal conversions in the nitrogen cycle are carried out by bacteria between the three 'reservoirs' of nitrogen and its compounds, namely the atmosphere, the soil (or water) and living organisms.

From nitrogen gas to ammonia (NH_3) - nitrogen fixation

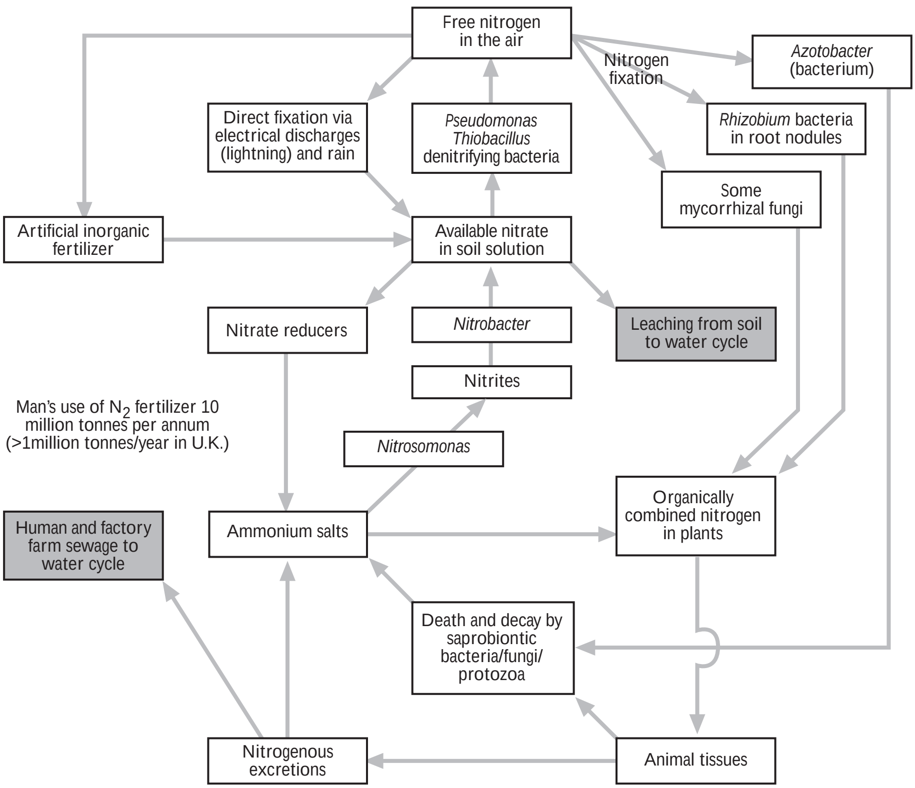
It is possible to make ammonia from gaseous nitrogen and hydrogen in the laboratory by combining them at high temperatures and pressures. This process is exploited commercially in the manufacture of nitrogen based fertilisers such as ammonium nitrate. **Nitrogen fixing bacteria** such as *Rhizobium* and *Azotobacter* can perform the same process at normal temperatures and pressures by means of the enzyme **nitrogenase**. They use the ammonia to make proteins and other organic nitrogen containing materials. One group of nitrogen fixing bacteria which includes *Rhizobium* (ref 3.1) forms a mutually beneficial mutualistic relationship with plants of the bean and pea family (**Papilionaceae**). *Rhizobium*, like *Azotobacter*, can live freely in the soil but it also penetrates the roots of these plants causing tumerous nodules to grow. Inside the nodules, the bacterial cells multiply, absorbing organic nutrients from the plant and giving, in exchange, a supply of fixed nitrogen.

From organic matter to nitrates in the soil - nitrification

Dead animals and plants, excreted materials, and faeces are broken down in the soil and water by decomposers. Proteins are digested in this process and the amino group containing nitrogen is split off from the resulting amino acids in the form of ammonia (NH_3). This process is called **deamination**. The activity of decomposers results in a pool of ammonia and ammonium compounds and this can be used as an energy source by a group of bacteria called **nitrifying bacteria** which includes the organisms *Nitrosomonas* and *Nitrobacter*. In contrast to green plants which derive their energy from the sun (**photoautotrophs**), *Nitrosomonas* and *Nitrobacter* use the energy derived from the oxidation of ammonium ions to nitrites and nitrates respectively. They are **chemoautotrophs** (ref 3.1).

From nitrates to nitrogen gas - denitrification

A third group of bacteria, called **denitrifying bacteria** use nitrates as a source of oxygen for their respiration. These organisms, which include *Pseudomonas* and *Thiobacillus* species are able to survive in soils which are waterlogged and lacking in oxygen and they release nitrogen gas as a waste product to the atmosphere, completing the nitrogen cycle.



Human influences on the nitrogen cycle

In nature, nitrogen fixation occurs faster than denitrification in all but winter waterlogged soils. Human activities add nitrogen compounds to the soil and water. There are three main sources of this nitrogen: fertilisers, animal excreta and domestic sewage, all of which lead to unnaturally high levels of nitrates in the water which may drain off the land.and enter rivers and lakes.

High nitrate levels in rivers and lakes stimulate the rapid growth of water plants, particularly microscopic algae. The growth of algae can be so extreme as to cause **algal blooms** (see section 3.6) which block out the light for other photosynthesising life forms and clog up filters in water purification plants. The end result of so much plant life is an equivalent excess of dead plant material which, in turn, stimulates a population explosion of aerobic decomposing bacteria. As the bacteria multiply and respire, they use up the available oxygen supply in the water. Ultimately, the water becomes depleted of animals like insect larvae and fish which require high oxygen levels, supporting instead increasing numbers of anaerobic microbes. Still water of this type becomes stagnant and smells of methane and hydrogen sulphide, the waste products of anaerobic bacteria.

The process of the addition of excess nitrates (and other inorganic nutrients e.g. phosphates) to rivers and lakes is called **eutrophication** (ref. 3.6). It occurs naturally in lakes which gradually accumulate increasing quantities of inorganic nutrients from their feeder streams and rivers. Human activities however vastly accelerate the process. It is estimated, for example that Lake Erie in Canada would have taken another 15 000 years to reach the its present state of eutrophication had it not been for the activities of humans.

Potentially, nitrates are one of the most serious of all pollutants of drinking water, as the soluble forms are not removed by the usual treatment process. There are vast amounts of nitrates slowly percolating down towards the underground water stores or **aquifers** which provide about 30% of the water supplies in Britain. As more and more aquifers become polluted with dangerous levels of nitrate, increasing attention is paid to the problems of nitrate removal at water purification works. Nitrates can be reduced to nitrites in the anaerobic conditions of the gut (particularly in the only slightly acid stomach of babies). The nitrites can oxidise the iron in haemoglobin to a form which cannot transport oxygen in the blood. This can produce a fatal anaemia in infants. Another danger is that of nitrites reacting with other compounds in the gut to form cancer forming nitrosamines.

◆ CHECKPOINT SUMMARY

- The principle conversions in the nitrogen cycle are between the three reservoirs of nitrogen and its compounds: the atmosphere, soil and water, and living organisms
- Nitrogen fixing microorganisms, e.g. *Rhizobium* bacteria can convert nitrogen to nitrogen containing organic compounds such as amino acids which are the building blocks of proteins
- *Rhizobium* forms a mutualistic association in the root nodules of certain plants (Papillionaceae)
- Dead organic matter decomposes and releases nitrogen containing compounds, e.g. ammonia. and ammonium compounds
- Chemosynthetic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* use these as a source of energy for their synthetic processes, which result in the production of nitrate ions
- Plants take up ammonium and nitrate ions and combine them into amino acids and proteins, and other nitrogen containing compounds, e.g. ATP and DNA
- Animals consume plants and each other and these nitrogen containing compounds form an essential part of the diets of consumers
- Animals die and decompose and the cycle continues
- Anaerobic denitrifying bacteria convert nitrates back to nitrogen
- Man now has a considerable effect on the Nitrogen cycle by the use of artificially produced nitrate fertilisers.

3.5
Energy Resources

Content

- How energy resources can be managed in a sustainable manner.
- The use of fossil fuels as illustrated by coal and oil.
- The use of renewable energy sources, as illustrated by fast-growing biomass, gasohol from sugar, biogas from domestic and agricultural wastes.

Fossil Fuels

The energy resources which power domestic and industrial machinery may be divided into two distinct categories; those which originate from photosynthesis e.g. fossil and biomass fuels, and those which do not. The latter variety include nuclear, hydroelectric, solar, wind, wave and volcanic power, all of which, with the exception of nuclear fuels, are dependent upon geographic location.

Most of the world's population depends on power generated from fossil fuels. In the process of photosynthesis, light energy trapped by chlorophyll in green plants is fixed in the C-C and C-H bonds of organic molecules synthesised from carbon dioxide and water. When biomass is burnt as fuel, the process of combustion reverses this sequence of events and the chemical energy in the organic matter is released as heat which may be used directly, or indirectly e.g. to generate electricity.

It is likely that the energy heating the filaments of your light bulbs was once locked up in organic molecules in plants which received the light of the sun many millions of years ago. Fossil fuels are the underground stores of biomass from previous ecosystems, compressed and changed in form from living material into coal, oil and gas. Most of the world's coal was formed some 300 million years ago in a period called the carboniferous period. The trees were not related directly to todays trees, but were giant ferns, now extinct. Over the geological ages, the remains of these trees were partially decomposed and then compressed under layers of new sediments. Oil deposits were formed by a similar process from the remains of marine animals and plants.

Biomass fuels from fast growing trees - a sustainable alternative to fossil fuels

The supply of fossil fuels can not be sustained indefinitely. It is therefore increasingly important that alternatives are developed to complement, or even replace the dwindling resources.

Fast growing biomass

Cutting trees for fuel is the oldest form of woodland management. Many trees sprout vigorous new shoots when cut, for example willow and eucalyptus. If the cut is made at the base of the tree the process is called **coppicing**, but where grazing animals such as deer can destroy the young shoots, the cut may be made higher up the trunk (fig 3.5.2). This is called **pollarding**. Both practices leave characteristic traces lasting many hundreds of years in ancient woodlands. The practice of coppicing has been revived in recent years using specially selected, fast growing tree species, notably poplars and eucalyptus. The rate of growth is, in any case, naturally accelerated by coppicing because all the resources of an extensive root system are diverted into a few slender shoots, and the wood can be harvested every 3 to 5 years on a rotation basis. In the future, it is likely that new genetically modified trees will be developed which will be able to grow quickly in relatively hostile climates and soils quite unsuitable for any other form of agriculture. In less developed areas of the world, the planting of fast growing hardwood trees is essential to prevent soil erosion (ref. 3.6) in addition to supplying firewood for cooking.

Gasohol from sugar

The harvesting and processing of agricultural crops leaves large amounts of waste biomass in the form of leaves, straw and other semi-processed materials, some of which might be fermented into alcohol for use as fuel. So far the commercial exploitation of alcohol from biomass has proved largely uneconomic. The 'gasohol' project in Brazil in the 1970s was based on alcohol production from a waste material (molasses) derived from sugar cane processing. The resulting ethanol was mixed 20 parts to 80 of petrol and used in cheaply converted car engines. Any benefit to the Brazilian economy from reduced fossil fuel imports, however, was quickly counterbalanced by the loss of revenue from selling the molasses to the international animal feed market, so the project floundered. The prospects are different for the future as new, genetically modified, varieties of yeast explode onto the biotechnology market. It is conceivable that almost any organic material might one day become a suitable substrate for commercial fermentation.

Biogas from domestic and agricultural waste

When waste is disposed of in landfill sites, the carbohydrate, protein and fat components of the organic matter are hydrolysed by aerobic microorganisms to produce acetate, carbon dioxide and hydrogen. In the process the available oxygen tends to be used up, and anaerobic bacteria take over to complete the decomposition of these compounds to methane and carbon dioxide. Methane is a valuable fuel (biogas) which burns with a colourless flame producing only carbon dioxide and water. A possible $40m^3$ of biogas could be produced by each tonne of waste, but recovery of this valuable product is relatively inefficient at present. Landfill biogas remains an important potential replacement for fossil fuels in both rich and poor countries.

The technology for collecting biogas is much more easily put into practice in sewage works where solid and semi-liquid organic matter is pumped into underground digester tanks. Similar systems can be installed on a smaller scale for the conversion of domestic and agricultural waste into usable fuel but the cost of construction and maintenance must be balanced against any concept of 'free' biogas energy.

◆ CHECKPOINT SUMMARY

- The use of fossil fuels (oil and coal) is unsustainable as they are finite resources. They represent the accumulation of millions of years of photosynthetic activity, and their combustion over the last century or so has returned all the carbon from these 'sinks' to the atmosphere
- The carbon cycle has become distorted and the carbon dioxide levels in the atmosphere are rising
- Energy resources can and need to be used in a sustainable manner
- To do so use must be made of solar energy, wind, wave, hydroelectric schemes, and organic matter the combustion of which represents a carbon balance
- Fast growing biomass (eucalyptus trees), gasohol (alcohol) from cane sugar, and biogas from the fermentation of domestic and agricultural wastes, release carbon dioxide by their combustion in proportion to that which was absorbed by photosynthesis in their production.

3.6
Human Influences on the Environment

Content

- The causes and effects of deforestation and desertification,with particular emphasis on communities, biodiversity and sustainable management.
- Atmospheric pollution (acid rain and greenhouse effect)
- Water pollution (effect of raw sewage and fertilisers on water quality, oxygen content and biodiversity, eutrophication, algal blooms).
- European legislation to control air and water quality.

Deforestation

Every year, large areas are deforested in order to create land for cultivation and to provide wood and charcoal for cooking. Once removed, overcultivation, overgrazing and the accompanying soil erosion change the soil conditions irreversibly so that regeneration of natural forest is impossible. It is estimated that the erosion of bare soil by wind and rain is 25 times more rapid than for land covered by a cotton crop, 4000 times more rapid than grassland and 32 000 times more rapid than forested land. In hilly regions, deforestation results in silt washing down with the rainwater into rivers, so that the river levels rise year by year causing annual floods in the plains and estuaries. Deforestation also has a major impact on local climate. Up to 50% of the water vapour of clouds above forests is contributed by transpiration. Without the trees, this water runs off into streams and rivers carrying with it valuable nutrients, leached from the soil. It is not recycled into the atmosphere.

The loss of natural vegetation and the accompanying loss of soil fertility affects the whole **community** of organisms which make up the biotic component of natural ecosystems. As you have seen (3.2), each individual population within a community is dependent on, and important to, a number of others. Intricate systems relate predators to prey, pollinators to flowering plants, consumers to producers. The loss of a single component can have dramatic knock on effects. For example, pollinating mechanisms can be so specific that the loss of a single pollinator in the ecosystem can result in the local extinction of an entire population of plants.

Biodiversity is the term used to describe the number of different interacting species supported by a particular habitat. In general, the richer the vegetation cover, the greater the biodiversity, but each community has complex interactions and different weak spots and these need to be understood if effective conservation management strategies are to be devised. At present the usual response of governments to the loss of wildlife habitats is the creation of living museums in the form of nature reserves and wildlife parks. The important question is rarely addressed, namely, how big does a nature reserve have to be to preserve biodiversity?

The answer is, much larger than is generally expected. Wandering herds require massive grazing areas and uninterrupted freedom of movement within these areas. The wildebeest and zebra which migrate up and down the Great Rift Valley of East Africa between Tanzania and Kenya are threatened much more by human settlement than by the notorious crocodiles of the Mara river. Many of the animals most at risk of extinction are at the top of food chains. The hunting area of top carnivores such as tigers or eagles is very large but the reproductive area is much larger still. For populations to survive, genetic diversity through outbreeding is essential and isolated national parks do not answer this problem

Desertification

Natural deserts like the Sahara are created by global climate changes and are defined by the amount of annual rainfall received (less than 50mm). Settled human existence is not possible in such hostile conditions because the soil can not support food crops. However human settlement does occur on the fringes of these areas, although attempts to gain food and support from soils which are poor in nutrients to start with, and which suffer a combination of heat and drought often result in an expansion of the desert, a process called **desertification**. Desertification is the result of using arid and semi arid soils in non-sustainable ways to produce crops, and the underlying cause is the pressure of expanding human populations. The areas most at risk are tropical grasslands receiving between 200 and 600 mm rainfall per year in one short wet season.

The pressure for food and cash crops from overpopulated land results in too many crops being planted and harvested from the same soil, leaving insufficient time for the natural restoration of fertility. Overcultivation also leaves the soil bare for extended periods when it is vulnerable to erosion. The effect is particularly severe on hillside plots where sudden rains can create gulleys and land slips. As more land is used for cultivation, less is available for grazing livestock. Overgrazing eliminates the natural regeneration of trees and shrubs and it reduces the population of native grasses which are so important in binding and trapping soil particles. These tend to be replaced by temporary, shallow rooted species which appear and disappear with the rains.

One way of increasing food yields from arid soils is to irrigate the soil, but this invariably leads to a build up of salt deposits in the soil (**salinisation**) and, in solving one problem, it creates another. Irrigation water leaves a crust of salt as it evaporates from the soil surface and, over a period of time, this salt deposit is leached downwards by drainage until it reaches the water table. The only way to remove the surface crust is periodically to flood the soil, and provide adequate underground drainage channels to take away the accumulated salt along with the flood water. Without adequate drainage, flooding may raise the water table to the level of plant roots bringing with it toxic concentrations of salt. If proper concern is shown for the environment, desalination installations may be needed to treat the drainage water before it can be returned safely to a river, so, even in highly technical projects such as those in California, the real costs of irrigation can easily escalate beyond economic viability.

Pollution

A pollutant is any substance released into the environment as a result of human activities which causes harm. Some pollutants are directly toxic to humans and other organisms: others become harmful as they accumulate in unnatural quantities. Nitrate applied to a crop in the form of fertiliser, for example, is valued as a mineral nutrient: it becomes a harmful pollutant only if it leaches out of the soil into aquatic ecosystems.

Carbon dioxide and the greenhouse effect

Carbon dioxide is a major component of a layer of gases called 'greenhouse gases' which accumulate in the atmosphere. Other greenhouse gases include methane (ref 3.5), chlorofluorocarbons (CFCs), nitrous oxide and ozone. In a greenhouse, light energy passes through the glass and warms up the contents. Heat is prevented from escaping by the glass panels and, as a result, the space inside warms up. In a similar, but not identical way, the layer of greenhouse gases serves to warm the earth. It is calculated that without the greenhouse layer, the earth's average temperature would drop by up to 30ºC.

Radiant energy from the sun is made up of a number of different wavelengths, from ultra violet (less than 400nm) to infra red (more than 700nm). Visible light includes all the wavelengths between these two i.e. 400 - 700nm. Light energy passes relatively easily through the gas layer to warm the earth's surface but heat energy radiating back from the earth consists of much longer wavelengths (4000 - 100 000nm) which do not pass through so easily. Much of this energy is instead absorbed and re-radiated back to earth, hence the warming effect.

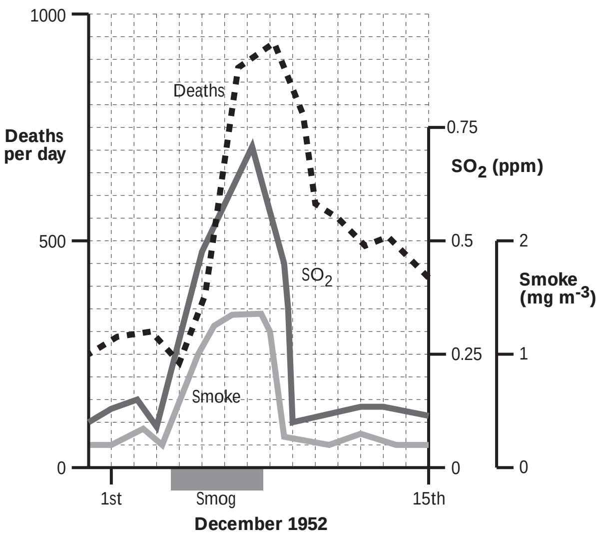
There is no doubt that the amount of carbon dioxide in the atmosphere has increased dramatically over the last few decades, and records show distinct evidence of global warming, but it should not be assumed that there is a direct connection between the two - correlation between two factors is not proof of a cause and effect relationship. The risk is, as yet, unknown and unquantifiable, but the wisest policy is to take steps to minimalise the risk by developing alternatives to fossil fuels.

Acid rain

Rain is always slightly acidic. It contains carbon dioxide which dissolves to form carbonic acid creating a normal pH of about 5.6. The term acid rain is defined as rainfall with a pH below 5. It is formed as sulphur dioxide (SO_2) and nitrogen dioxide (NO_2), originating from the combustion of coal and oil, react with moisture in the air to form sulphuric and nitric acids respectively. The rain in central Europe has an average pH of 4.1 whilst water droplets in fog may be as low as pH 2.5. At these levels, acid rain can cause serious harm to human health. In December of 1952, for example, London was enveloped in a notorious fog which remained static due to unusual air currents.

The pH was estimated to be about 1.6 and 4000 people died from related illnesses. The cause of this disaster was identified as smoke form the countless chimneys of London but, in fact, the major source of sulphur dioxide pollution is from coal fired power stations. Sulphur occurs as an impurity in coal (up to 3% by mass). Furthermore, the smoke from industrial chimneys may carry these gases hundreds of kilometres away from the original source so the effects of pollution extend over whole continents.

Pollution levels in the London smog of 1952



Acid rain lowers the pH of the soil solution where the excess H^+ ions tend to replace ions such as Ca^{2+}, K^+ and Mg^{2+} held by the soil particles, which are essential for plant growth. These nutrients leach out and are lost in the drainage water. Nitrate (NO^{3-}) ions from nitric acid are not a major problem because they are taken up by plant roots and used as a nitrogen source, but sulphate (SO^{4-}) ions move freely through the soil solution carrying H^+ ions with them into surrounding water systems. Acid rain therefore has the effect of removing plant nutrients from the soil, but plants are affected in more direct ways as well. The leaves of evergreen plants, particularly coniferous trees, are protected by a waxy layer (cuticle) which is eroded by acid rain. Over a period, nutrients are also lost from the leaves causing a die back of the crown of the tree.

Acid rain can have even more drastic effects on lakes and waterways. The exoskeletons of crayfish and shrimp become soft and susceptible to fungal attack at pH levels below 5.5, and no fish survive at levels below 4.5. In studies on Scandinavian lakes the loss of brown trout and salmon was linked to two different consequences of acid rain. One was the denaturation of an enzyme, essential to the hatching of eggs. The other was the leaching of Al^{3+} ions into lakes from the surrounding soil which caused the secretion of large amounts of mucus by the fish gills. As a result gas exchange and osmoregulation became impaired and the fish died.

◆ CHECKPOINT SUMMARY

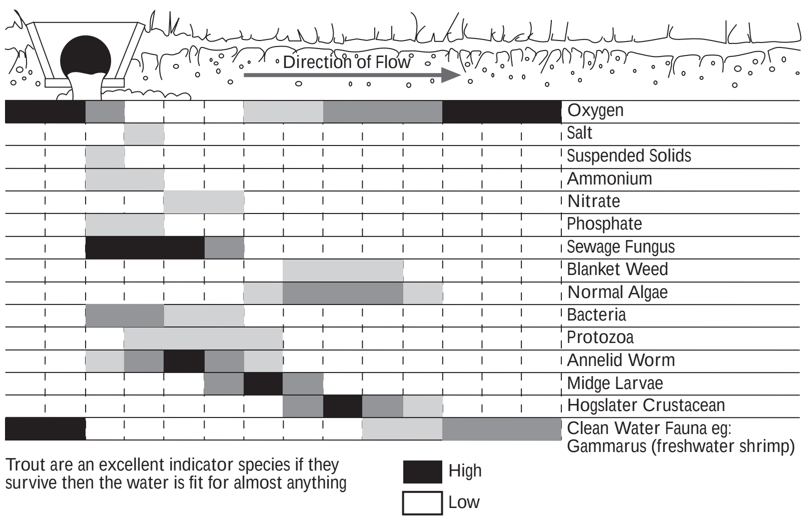
- Increasing population pressure and economic demands lead to deforestation. Removal of tree cover on poor soils can lead to the collapse of the entire ecosystem and the formation of deserts (desertification)
- Under less extreme conditions deforestation can lead to isolation of small patches of woodland which are insufficient to support the original forest communities with their rich biodiversity
- If the cleared areas are used for crop production there is a dramatic drop in the biodiversity and hence stability of communities, and massive monocultures are prone to pest attack
- Atmospheric pollution as a result of the combustion of fossil fuels results in acid rain (sulphuric and nitric acids), and greenhouse gases (e.g. carbon dioxide) which absorb solar radiation and lead to a warming of the atmosphere.

Organic pollution and eutrophication

Farmyard waste in the form of manure and silage liquid, and untreated domestic sewage contains large amounts of organic matter which can cause serious pollution problems if allowed to enter rivers and lakes. This material provides food for a multitude of anaerobic microorganisms in aquatic ecosystems and as these organisms complete the process of decomposition, they use up valuable oxygen supplies. Aquatic organisms may be classified according to their oxygen need; those with the greatest need are **indicator species** for the cleanest water, that is their presence indicates water unpolluted by organic matter.

The direct link between organic pollution and oxygen availability is the basis of a test for water purity called the **BOD** (Biological Oxygen Demand) test. BOD is the amount of oxygen required by microbes to decompose the organic matter present in a water sample. Water samples are collected in glass bottles and an initial measurement of their oxygen content is taken using an oxygen meter. The samples are incubated in the dark at 20ºC for 5 days and then the oxygen content is re-measured. The difference between the two readings gives the BOD (in mg O_2 dm^{-3}). It varies from 0 - 12 in clean rivers to 250 in untreated sewage.

The decomposition of organic matter releases inorganic nutrients into water systems which can be just as damaging to the environment (ref. 3.4). The presence of excess nutrients initiates a process called **eutrophication** (from the Greek words *eu* - well, *trophe* - fed) 'Well fed' algal populations can undergo rapid population 'explosions' into algal 'blooms' on the surface of the water, blocking light penetration and providing a further source of organic material at the end of the growing season. Fertilisers (3.5) and farmyard wastes are the main sources of inorganic nutrients, but even treated sewage can contain large quantities of phosphates from detergents.



European legislation for air and water purity

Anti-pollution measures to safeguard air and water purity tend to be long term, expensive, and unpopular with the commercial sectors. It is hardly surprising, therefore, that few national governments concern themselves seriously with environmental issues. Political pressure and national sentiments are generated more when the environmental threat crosses national boundaries. The European Community legislation focusses its attention mainly on the transboundary (international) pollution of air and water through international conventions and agreements, but it also translates these agreements into specific Directives which become binding on the member states, some examples of which are given below.

Water protection and management

International agreements and **conventions** exist with regard to the conservation of marine and coastal waters, and the major European rivers. These include currently, for example, a convention for the protection of the marine environment of the north eastern Atlantic, protocol concerning specially protected areas and biodiversity in the Mediterranean, and conventions of the International Commission for the protection of the rivers Elbe and Oder.

International agreements of this kind define areas of common interest but have less immediate effect than the **Council Directives** which tend to be much more specific, and thus easier to define and enforce, for example; regulations regarding minimum levels of drinking water purity from ground and surface sources, prohibitions on the discharge of hydrocarbons from boats, nitrates from agricultural land and mercury from chlor-alkali industries.

Council Directives must be adopted as law by member states after a given time, typically 18 months after the formulation of the legislation by the EC. It is then up to the Department of the Environment or equivalent bodies to enforce them in the individual European countries.

Monitoring of atmospheric pollution

As for air quality, European legislation may be divided into two broad categories: conventions and agreements about transboundary pollution and Council Directives to specify limits and controls within the member states. The major transboundary issues are sulphur dioxide and nitrous oxide emissions and their long range effects; the control of greenhouse gases; and the depletion of the ozone layer. Some Council Directives are aimed at the major industries, for example, testing and monitoring emissions of carbon dioxide, carbon monoxide, suspended particles, sulphur dioxide and oxides of nitrogen from chemical works and power plants; controlling the release of chlorofluorocarbons from foamplastics and refrigerant industries. Others have had a direct effect on daily life, for example, Directives about lead in motor fuels and the monitoring of pollutants from diesel engines for use in vehicles.

European legislation is not exactly watertight. The conventions have limited force because they are simply international agreements, and the Council Directives suffer from the time lag between formulation and adoption. If a member state 'breaks the rules' it can take a very

◆ CHECKPOINT SUMMARY

- ◆ Water pollution results from the release of the many toxic waste products of man into the water system
- ◆ Acid rain acidifies water and destroys aquatic ecosystems
- ◆ Raw human and animal sewage has a high organic content and its oxidation by aerobic microorganisms depletes water of its oxygen
- ◆ Run-off of excess nitrates and phosphates from artificial fertilizers in the soil cause eutrophication of the water which can trigger excess algal growth (algal blooms), which can deplete other essential nutrients, leading to death of the algae, their aerobic decomposition, and depletion of oxygen in the water
- ◆ Depletion of oxygen in aquatic ecosystems leads to the death of aerobic organisms and the collapse of the ecosystem into anaerobic conditions, which cannot be simply reversed by oxygenation
- ◆ European legislation exists to control air and water quality.

long time for the rest of the community to exercise some form of censure. It can also be argued that environmental issues such as the greenhouse effect, ozone depletion and marine pollution are global, not just European.

Balancing these negative aspects, it should be remembered that Directives such as those controlling diesel fuel emissions, lead, nitrate and mercury pollution have measurably improved the quality of the air we breathe in our cities and the water we drink. On the wider scene, the focus by the EC on transboundary environmental pollution helps to create an impetus for international agreements on a global scale.