Constructing pyramids of energy

MEASURING ENERGY FLOWS IN ECOSYSTEMS

Collecting the data needed to construct a pyramid of energy is very time-consuming and has only been done fully for a few ecosystems. Energy flow through each species in the ecosystem must be measured and then the species are classified into trophic levels.

The lowest bar of a pyramid of energy is the total amount of energy that flows through the producers in the ecosystem. This is also called the gross production.

Gross production is the total amount of organic matter produced by plants in an ecosystem. Gross production and all the other energy flows in a pyramid are measured in kilojoules of energy per square metre per year (kJ m^{-2} $year^{-1}$).

Gross production does not have to be measured directly, as it can be calculated from net production and plant respiration.

Net production is the amount of gross production of an ecosystem remaining after subtracting the amount used by plants in respiration.

gross production = plant respiration + net production

Example – an old field community in Michigan, USA

net production = 20.79×10^3 kJ m^{-2} $year^{-1}$

plant respiration = 3.68×10^3 kJ m^{-2} $year^{-1}$

gross production = $(20.79 + 3.68) \times 10^3$ kJ m^{-2} $year^{-1}$

= 24.47×10^3 kJ m^{-2} $year^{-1}$

The upper bars of a pyramid of energy are the total amounts of energy that flow through the various groups of consumers. This is the amount of energy in the food that the consumers ingest.

CLASSIFYING ORGANISMS INTO TROPHIC LEVELS

When real food webs are constructed, many species are seen to exist partly in one trophic level and partly in another.

The following examples illustrate this.

- *Euglena*, a unicellular organism found in ponds, has chloroplasts and photosynthesizes, but it also feeds heterotrophically by endocytosis.
- Chimpanzees mainly feed on fruit and other plant matter, but they also sometimes eat termites and even larger animals such as monkeys, so they are both first and second consumers.
- Herring are second consumers when they feed on *Calanus* and other first consumers (right), but they are third consumers when they feed on sand eels and other second consumers.
- Oysters (*Ostrea* species) and many other filter feeders consume both ultraplanktonic producers and microplanktonic consumers, so they are first and second consumers. They also consume dead organic matter, so they are also detritivores.

It is difficult to decide into which trophic level these types of organism should be classified. The only practical solution is to classify each species according to its main food source.

USING DATA TO CONSTRUCT A PYRAMID OF ENERGY

The data below was obtained from an Arctic tundra ecosystem on Devon Island in northern Canada.

Trophic level	Energy flow (kJ m^{-2} $year^{-1}$)
Producers	4925
Primary consumers	24
Secondary consumers	4

This data can be used to construct a pyramid of energy. Each bar of the pyramid should be drawn to the same scale and labelled with the trophic level. Other examples are shown on page 39.

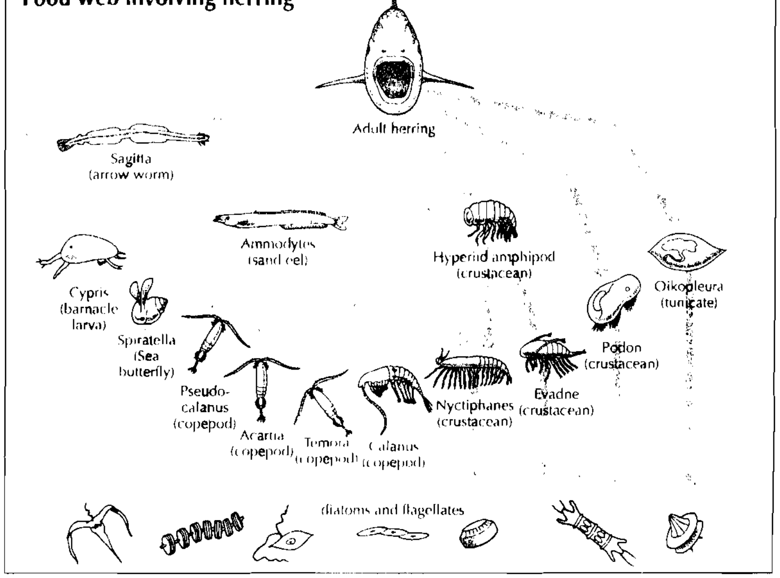
REASONS FOR SMALL NUMBERS AND LOW BIOMASS OF ORGANISMS IN HIGHER TROPHIC LEVELS

Pyramids of energy show that there are large losses of energy at each trophic level. The reasons for these losses of energy are explained on page 38. Losses of energy in ecosystems are accompanied by losses of biomass.

Biomass is the total dry mass of organic matter in organisms or ecosystems.

Respiration is an example of a process in which both energy and biomass are lost. When glucose or another respiratory substrate is oxidized in respiration, energy from the glucose is released for use in the cell and is then lost as heat. The mass of the glucose does not disappear – it passes into the carbon dioxide and water that are produced in respiration. When these waste products are excreted, biomass is lost. As a result of respiration and other processes, both energy and biomass are lost at each stage in a food chain. The energy content per gram of food does not decrease along a food chain. If anything, the food eaten by the higher trophic levels is richer in energy per gram than that eaten by lower trophic levels. However, the total biomass of food available to higher trophic levels is very small. It cannot support large numbers of organisms, especially as these organisms need to be large to overpower their prey. Higher trophic levels therefore usually contain very small numbers of large organisms, with a low total biomass per unit area of ecosystem.

Food web involving herring

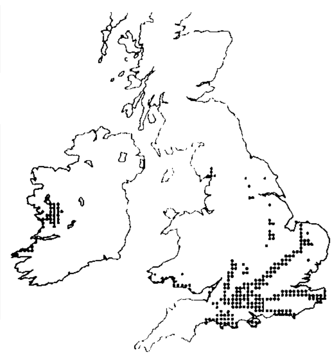


FACTORS AFFECTING THE DISTRIBUTION OF PLANT SPECIES

The distribution of a species is the range of places that it inhabits. The distribution of plants is closely linked to the levels of abiotic factors in the environment. The main abiotic factors are temperature, water, light, soil pH, salinity and mineral nutrients. *Avicennia germinans*, for example, is a tree found in mangrove swamps on the coast of Mexico. It grows where the climate is hot and the soils are waterlogged and anaerobic, with high levels of salinity, a pH close to neutral and high levels of mineral nutrients. Few plants can grow in these conditions, but *Avicennia germinans* thrives.

Sometimes the distribution of a plant species shows what conditions a plant prefers. The figure shows the distribution of *Asperula cynanchica* in Britain and Ireland. It is found in areas with alkaline soils formed from chalk or limestone rock. It is absent from colder northern areas even where the soils are alkaline.

Distribution of *Asperula cynanchica* (Squinancy Wort)



FACTORS AFFECTING THE DISTRIBUTION OF ANIMAL SPECIES

The distribution of animal species is affected by both abiotic and biotic factors.

- **Temperature** – all animals are affected by external temperatures, especially those that do not maintain constant internal body temperatures. Extremes of temperature require special adaptations, so only some species can survive them.
- **Water** – animals vary in the amount of water that they require. Some animals are aquatic and must have water to live in and at the other extreme some animals including desert rats are adapted to survive in arid areas where they are unlikely ever to drink water.
- **Breeding sites** – all species of animals must breed at some stage in their life cycle. Many species need a special type of site and can only live in areas where these sites are available. For example, mosquitoes need stagnant water for egg laying.
- **Food supply** – many species of animal are adapted to feed on specific foods and can only live in areas where these foods are obtainable. For example, blue whales feed mainly on krill and so congregate in areas of the ocean where krill is abundant.
- **Territory** – some species of animal establish and defend territories, either for feeding or breeding. This tends to give the species an even rather than a clumped distribution. Pairs of tawny owls defend a single territory throughout their adult lives, for example.

ECOLOGICAL SUCCESSION

An ecological succession is a series of changes to an ecosystem, caused by complex interactions between the community of living organisms and the abiotic environment. The community causes the abiotic environment to change and as a result some species die out and others join the community. Although the community may continue to change in this way for hundreds of years during a succession, eventually a stable community develops, called the climax community.

The changes to the abiotic environment during ecological successions vary, but some often occur.

- The amount of organic matter in the soil increases as organic matter released by plants and other organisms accumulates.
- The soil becomes deeper as organic matter helps to bind mineral matter together.
- The soil structure improves as the organic matter content rises, increasing the amount of water that can be retained and the rate at which excess water drains through.
- Soil erosion is reduced by the binding action of the roots of larger plants.
- The amounts of mineral recycling increases, as the soil can hold larger amounts and more is held in the increasing biomass of the community.

AN EXAMPLE OF SUCCESSION

On the slopes of Volcan Osorno, in southern Chile, there are large areas of bare volcanic ash, released during recent eruptions of the volcano. Adjacent areas show the stages in an ecological succession.

- Mosses spread over the ash, eventually forming a complete cover.
- Small herbs join the mosses.
- Shrubs, including *Pernettya, Eucryphia* and *Embothrium*, enter the community and gradually replace the herbs and mosses (below).
- Trees, including *Nothofagus*, gradually spread to replace the shrubs with dense forest.

A stage in succession to forest on Volcan Osorno

Ecological niches

INTERACTIONS BETWEEN SPECIES

All living organisms are affected by the activities of other living organisms. A situation in which two species affect each other is called an interaction. The table below shows a classification of interactions.

Interaction	Terrestrial example	Marine example
Herbivory – a primary consumer feeding on a plant or other producer. The producer's growth affects food availability for the herbivore	The beetle *Epitrix atropae* feeds only on leaves of *Atropa belladonna*, often causing severe damage to them. To most other organisms the leaves are highly toxic	Algae growing on rocks in shallow seas are often heavily grazed. For example, a snail *Lacuna pallida* feeds on the brown seaweed *Fucus serratus* on rocky shores in Europe
Predation – a consumer feeding on another consumer. The numbers and behaviour of the prey affect the predator	The Canada lynx is a predator of the arctic hare. Changes in the numbers of hares (up or down) are followed by similar changes in lynx numbers	Bonitos feed on anchovetas in the Pacific Ocean west of Peru. When the anchoveta population crashed in the 1970s starving bonitos were found, with completely empty stomachs
Parasitism – a parasite is an organism that lives on or in a host and obtains food from it. The host is always harmed by the parasite	The tick *Ixodes scapularis* is a parasite of deer and of white-footed mice in northeast USA. The tick feeds by sucking blood from its hosts and therefore weakens them	Organisms that cause infectious diseases are all parasites. For example, *Sphingomonas* bacteria cause a disease in elliptical star corals on the Florida reef
Competition – two species using the same resource compete if the amount of the resource used by each species reduces the amount available to the other species	Douglas Fir and Western Hemlock grow together in mixed forests in Oregon and other states in northwest USA, competing with other each other for light, water and minerals	Species of coral compete with each other on coral reefs. *Pocillopora damicornis* competes with many other corals, including *Pavona varians*, which benefit when predators feed on *Pocillopora damicornis*
Mutualism – mutualists are members of different species that live together in a close relationship, from which both benefit	*Usnea subfloridana* and other lichens consist of a fungus and an alga growing mutualistically. The alga supplies foods made by photosynthesis and the fungus absorbs mineral ions	The cleaner wrasse is a small fish of warm tropical seas that cleans parasites from the gills and body of larger fish such as reticulate damselfishes. The cleaner benefits because the parasites that it removes are its food

THE NICHE CONCEPT

Studies of the distributions of organisms and of interactions between organisms show that there are many different ways of existing in an ecosystem. The mode of existence of a species in an ecosystem is its ecological niche.
The niche includes:

- habitat – where the species lives in the ecosystem.
- nutrition – how the species obtains its food.
- relationships – the interactions with other species in the ecosystem.

If two species have a similar niche, they will compete in the overlapping parts of the niche, for example for breeding sites or for food. Because they do not compete in other ways they will usually be able to coexist.
However, if two species in an ecosystem have exactly the same niche they will compete in all aspects of their life and one of the two species will inevitably prove to be the superior competitor. This species will cause the disappearance of the other species from the ecosystem.
The principle that only one species can occupy a niche in an ecosystem is called the **competitive exclusion principle.**

Ecologists often use statistics in their investigations. The use of the mean and standard deviation is described on page 36. The uses of two other statistics are described on this page.

THE *t*-TEST

The *t*-test can be used to find out whether there is a significant difference between the means of two populations. There are several versions of the *t*-test, with different formulae, for use in different situations. The formula shown below is used when the standard deviations of the two populations are not known, but are assumed to be equal, and both populations can be modelled on the normal distribution.

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$\bar{x}$ = mean.
s = estimate of common standard deviation.
n = number of entries in a set of data.
degrees of freedom = $(n_1 + n_2 - 2)$.

It should be noted that t is nearly always now calculated using computer software and it is more important to be able to choose the correct formula than to learn one particular formula.
When t has been calculated, it is compared with a table of critical values (below). The correct line of the table must be used, corresponding to the number of degrees of freedom. If the calculated value is greater than the relevant critical value, the difference between the means is considered to be significant.

Table of critical values of *t*

Degrees of freedom	Level of significance (P) 0.2	0.1	0.05	0.02	0.01	0.002
1	3.078	6.314	12.706	31.821	83.657	318.310
2	1.886	2.920	4.303	6.985	9.925	27.327
3	1.638	2.353	3.182	4.541	5.841	10.215
4	1.533	2.132	2.776	3.747	4.604	7.173
5	1.476	2.015	2.571	3.365	4.032	5.893
6	1.440	1.943	2.447	3.143	3.707	5.208
7	1.415	1.895	2.385	2.998	3.499	4.785
8	1.397	1.860	2.308	2.896	3.355	4.501
9	1.383	1.833	2.262	2.821	3.250	4.297
10	1.372	1.812	2.228	2.764	3.169	4.144
11	1.363	1.796	2.201	2.718	3.106	4.025
12	1.356	1.782	2.179	2.681	3.055	3.930
13	1.350	1.771	2.180	2.650	3.012	3.852
14	1.345	1.761	2.145	2.624	2.977	3.787
15	1.341	1.753	2.131	2.602	2.947	3.733
16	1.337	1.746	2.120	2.583	2.921	3.686
17	1.333	1.740	2.110	2.567	2.898	3.646
18	1.330	1.734	2.101	2.552	2.878	3.610
19	1.328	1.729	2.093	2.539	2.861	3.579
20	1.325	1.725	2.086	2.528	2.845	3.552

Example – sizes of two groups of lichens

To test whether there was any difference in the size of lichens growing on the top and side of a stone wall, some data were collected. The diameters of a random sample of ten lichens on the top and ten on the side were measured and a *t*-test was used to find out if there was a significant difference.

Surface	**Diameter of lichen (mm)**									
Top	22	10	24	45	9	26	5	34	10	13
Side	22	12	23	13	7	13	5	24	3	10

Mean diameters: top = 19.8 mm   side = 13.2 mm

t = 1.406 (calculated using the equation shown above). When this value is compared with critical values (for 18 degrees of freedom and P = 0.05) we see that 1.406 is less than 2.101, so there is no significant difference between the mean diameters on the two surfaces. If a larger sample size was used, for example one hundred lichens on each surface, the difference might be shown to be significant.

THE SIMPSON DIVERSITY INDEX

It is sometimes useful to have an overall measure of species richness in an ecosystem. The Simpson index is one of the most commonly used.

Method

1. Use a random sampling technique to search for organisms in the ecosystem.
2. Identify each of the organisms found.
3. Count the total number of individuals of each species.
4. Calculate the index (D).

$$D = \frac{N(N-1)}{\sum n(n-1)}$$

N = total number of organisms.
n = number of individuals of each species.

Example – species richness in a river in Sweden

Organisms were found and identified in the River Enningdalselva in a part of Sweden where some lakes and rivers have been affected by acid rain. Six sites in the river were chosen randomly and kick sampling was used at each site along a 10 m transect. Nets with a 25 cm × 25 cm opening and 0.5 mm mesh were used. The results are shown below.

Group	Species	Name	Count
Ephemerida	*Dixa* sp.	Mayfly larva	8
Odonata	*Tipula* sp.	Dragonfly larva	5
Trichoptera	Sp. unidentified	Caddis fly larva	4
Plecoptera	*Nemoura variegata*	Stonefly larva	4
Hemiptera	*Gerris* sp.	Pond skater	3
Isopoda	*Asellus aquaticus*	Water louse	2
Acari	*Arrhenurus* sp.	Water mite	1
Platyhelminth	*Dendocoelum lact.*	Flatworm	4
Platyhelminth	*Dugesia* sp.	Flatworm	3
Hirundinea	Sp. unidentified	Leech	1
Oligochaeta	*Lumbriculides*	Annelid worm	2
Gastropoda	*Lymnaea* sp.	Snail	4
Bivalvia	*Margaritifer*	Pearl mussel	1

$$D = \frac{42\ (42-1)}{140} = 12.3$$

The high diversity index suggests that the river has not been damaged by acid rain, or any other disturbance. This fits in with observations of a thriving salmon population in the river.

USES OF THE SIMPSON DIVERSITY INDEX

Sampling and calculation of the diversity index each year, using exactly the same methods, allows monitoring of the health of the ecosystems like the River Enningdalselva. Sampling of a group of similar ecosystems, for example a group of rivers in an area, allows comparison of their health. Identification of high-diversity ecosystems allows informed decisions to be made about priorities in wildlife conservation.

Biodiversity

The word biodiversity was only invented in 1986. It is an abbreviation of 'biological diversity' and encompasses the diversity of ecosystems on Earth, the diversity of species within them, and the genetic diversity of each species.

REASONS FOR THE CONSERVATION OF BIODIVERSITY

Economic reasons

- New commodities, for example medicines or materials may be found in organisms growing in the wild.
- New crop plants or farm animals could be developed from wild species or existing varieties could be improved using genes from wild species.
- Ecotourism could provide considerable income.

Ecological reasons

- Native species are adapted to local conditions, whereas alien species that might replace them are unlikely to be so well adapted.
- Species in natural communities are interdependent, so if one species becomes extinct the rest of the community is threatened.
- Damage to ecosystems can have widespread effects including soil erosion, silting up of rivers, flooding and even changes to weather patterns.

Ethical reasons

- Every species has a right to life, regardless of whether it is useful to humans or not.
- The wildlife of each area has cultural importance to the local human population and it is therefore wrong to destroy it.
- It would be wrong to deprive humans in the future of the rich experiences that the Earth's biodiversity provide to us.

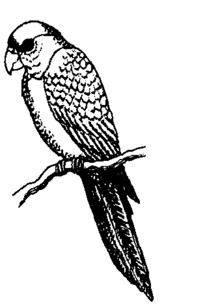
Esthetic reasons

- Natural ecosystems and species in the wild are beautiful and give us great enjoyment.
- Painters, writers and composers have been inspired by nature around them.

EXTINCTION OF SPECIES

When the last members of a species die, the species becomes extinct. The rate of species extinctions is probably at an all-time high at the moment, as a result of human activities. There are unfortunately many extinct species from which to select examples for study, including the passenger pigeon and the dodo. Two less famous examples are described here.

1. *Conuropsis carolinensis* – the Carolina Parakeet

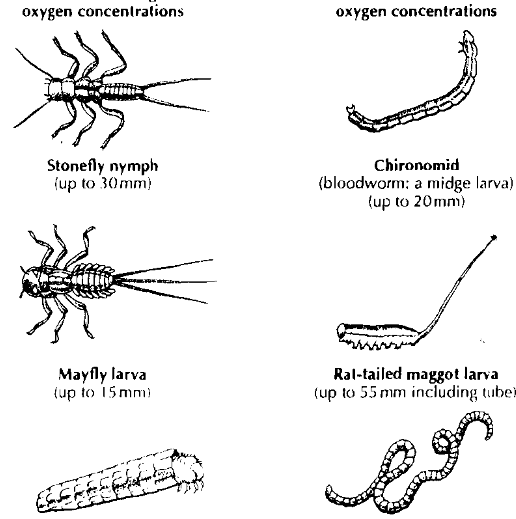


These brightly coloured parrots were once common in forests to the east of the Mississippi, from New York to Florida, feeding on seeds of trees and herbs. Clearance of forests reduced their habitat and they started to feed on crops. Farmers killed many of them. Others were caught to obtain feathers, which were used to make fashionable women's clothing. They were also trapped and kept as pets. By 1900 there were no Carolina Parakeets in the wild and the last specimen died in Cincinnati Zoo in 1918.

MONITORING ENVIRONMENTAL CHANGE

Problems in natural ecosystems can be detected quickly if there is frequent environmental monitoring. Abiotic factors can be measured directly, but another technique is the use of living organisms to detect changes. Indicator species are very useful, as they need particular environmental conditions and therefore show what the conditions in an ecosystem are. Lichens are valuable indicator species because their tolerance of sulphur dioxide varies considerably from the most tolerant to the least tolerant species. Indicator species are also often used to assess pollution levels in aquatic ecosystems. Stonefly, mayfly and caddis fly larvae (below) require unpolluted, well-oxygenated water. Other aquatic species, including chironomid midge larvae, rat tailed maggot larvae and tubifex worms indicate low oxygen levels and excessive levels of suspended organic matter, from untreated sewage for example. The indicator species found in the River Enningdalselva (page 157) show how unpolluted it was.

Indicator species is aquatic ecosystems



To obtain an overall environmental assessment of a river or other ecosystems, a biotic index can be calculated. There are various methods, which usually involve multiplying the number of individuals of each indicator species by its pollution tolerance rating. An abundance of tolerant species gives a low overall score and an abundance of intolerant species gives a high score.

2. *Calochortus indecorus* – the Sexton Mountain mariposa lily

Calochortus indecorus was discovered growing over a small area on Sexton Mountain in Oregon. The building of an interstate highway destroyed the habitat and with it this rare plant disappeared. No other sites are known where *Calochortus indecorus* grows, so it is almost certainly extinct

NATURE RESERVES AND *IN SITU* CONSERVATION

The best place to conserve a species is in its own habitat. This is called *in situ* conservation. Many terrestrial and marine nature reserves have been established for this purpose. *In situ* conservation has several advantages.

- Species remain adapted to their habitats.
- Greater genetic diversity can be conserved.
- Animals maintain natural behaviour patterns.
- Species interact with each other, helping to conserve the whole ecosystem.

Despite these advantages, *in situ* conservation is not always enough to ensure the survival of a species.

- Some species become so rare that it is not safe to leave them unprotected in the wild.
- Sometimes destruction of a natural habitat makes it essential to remove threatened species from it.

In these situations *ex situ* measures are needed.

MANAGEMENT OF NATURE RESERVES

Nature reserves often need active intervention – this is called management.

- Alien species must be eliminated, especially alien species of predator and invasive plants.
- Areas that have been degraded by human activities must be restored.
- Special measures may be needed to help encourage threatened species, supplementary feeding or clearing vegetation, for example.
- Exploitation by humans must be controlled, for example the hunting of animals for bushmeat.

INTERNATIONAL ORGANIZATIONS AND CONSERVATION

Wildlife does not recognize frontiers between countries, so international co-operation over conservation is vital. Both voluntary and governmental agencies have important roles.

WWF – an example of a voluntary organization

The World Wildlife Fund is the largest privately supported conservation organization in the world, with millions of members and over 10 000 conservation projects so far undertaken. WWF is involved in political lobbying, monitoring of endangered species and establishing nature reserves. It also tries to involve local populations in conservation projects.

CITES – an example of a governmental organization

The Convention on International Trade in Endangered Species is the largest conservation convention, with over 100 member states. It regulates trade in threatened wild plant and animal species. Every 2 years there is a review of the species that are listed in two appendices to the convention. Trade in species listed in Appendix I is banned. Trade in species listed in Appendix II is only allowed with a licensing system that allows the trade to be monitored. The African elephant and the Alerce tree of South America are examples of species listed in Appendix I. Listing of the African elephant in 1989 stopped the rapid fall in numbers caused by poaching.

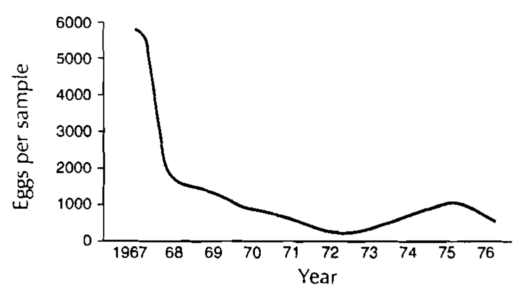
EX SITU CONSERVATION

1. **Captive breeding** – some or all members of a species are caught and moved to a zoo, where they are encouraged to breed. When numbers are high enough, some are returned to the wild to re-establish a natural population. An example of a species helped by captive breeding is the Hawaiian kestrel.
2. **Botanic gardens** – sites where many different species of plants are cultivated, either in greenhouses or in the open. One of the largest, Royal Botanic Gardens of Kew has more than 50 000 of the world's 250 000 known species in its collection.
3. **Seed banks** – seeds are kept in cold storage at –10 °C to –20 °C. Seeds of most species remain viable for more than a hundred years in these conditions. Other species that are not as long lasting can be germinated and grown to produce replacement seed before viability is lost. The Kew Millennium Seed Bank will eventually hold seed of 25 000 endangered species.

CONSERVATION OF FISH

Wild populations of fish are an important food source for many human populations. If a population is overexploited and the numbers of adult fish fall below a critical level, spawning fails. The disastrous collapse in the Peruvian anchoveta fishery is an example of this. Industrial scale exploitation of the anchoveta began in 1940 and grew at a rapid rate until 1973, when the annual catch dropped from 12 million tonnes to zero. The fall in anchoveta egg production in the years preceding the population crash is shown below. An El Niño event was partly responsible, but over-fishing was also a major factor. The anchoveta is a key species in its ecosystem. Many predators rely on it for food, including bonitos, cormorants, gannets and pelicans and populations of all of these species were greatly reduced.

Graph showing a collapse in anchoveta egg production



International measures are needed to promote fish conservation because most fish live in international waters, where ships from any country can catch fish. Various measures would help.

- Monitoring of stocks and of reproduction rates.
- Quotas for catches of species with low stocks.
- Moratoria on catching endangered species.
- Minimum net sizes, so that immature fish are not caught.
- Banning of drift nets, which catch many different species of fish indiscriminately.

Some of these measures have been used already in parts of the world, with limited success. Enforcement is very difficult and relies on a level of international trust and co-operation that is not always seen.

HL Nitrogen cycle

BIOGEOCHEMICAL CYCLES

All chemical elements in living organisms can be reused endlessly, as a result of biogeochemical cycles. These cycles involve living organisms, the atmosphere, water and land. There are two alternating sections in most biogeochemical cycles.

Inorganic forms of the element are absorbed from the environment by autotrophic living organisms and are converted into complex organic forms

The organic forms of the element are passed along food chains but are ultimately converted back into an inorganic form and released into the environment

The carbon cycle is described on page 43.
The nitrogen cycle is shown below.

THE ROLE OF BACTERIA IN THE NITROGEN CYCLE

Bacteria have many essential roles in the nitrogen cycle.

1. Nitrogen fixation

Free-living *Azotobacter* and *Rhizobium* living mutualistically in root nodules both fix nitrogen. Nitrogen fixation is conversion of nitrogen from the atmosphere into ammonia, using energy from ATP.

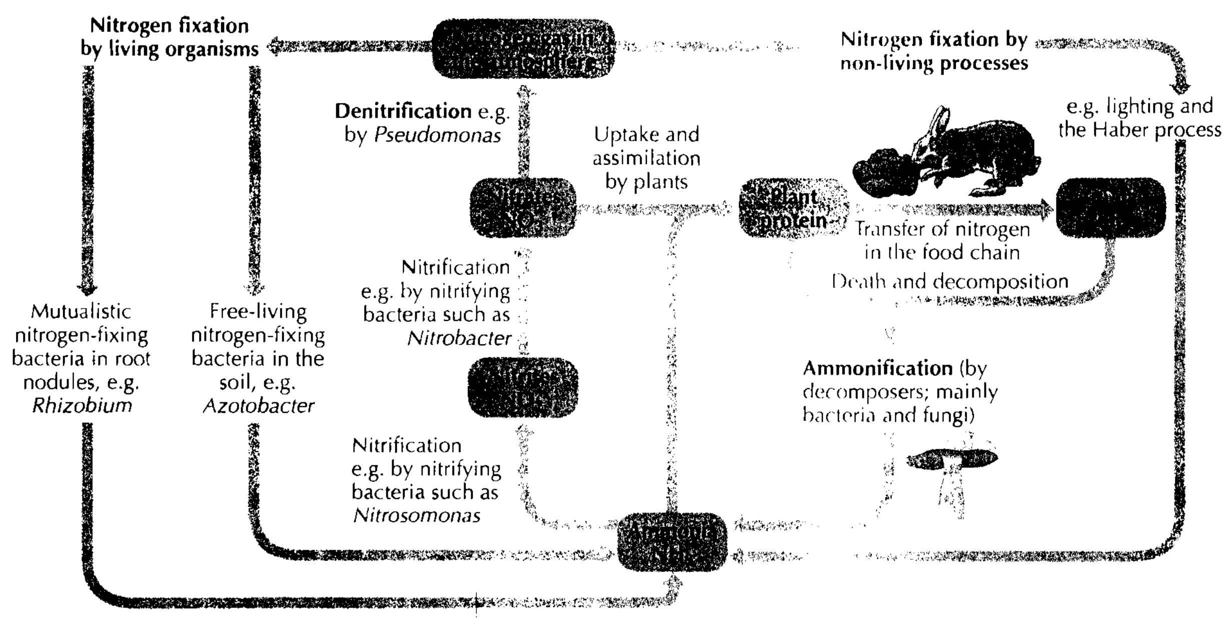
2. Nitrification

The conversion of ammonia to nitrate (nitrification) involves two types of soil bacteria. *Nitrosomonas* converts ammonia to nitrite and *Nitrobacter* converts nitrite to nitrate. Nitrification happens very rapidly, as long as soils are well aerated with abundant supplies of oxygen.

3. Denitrification

Nitrate is sometimes converted into nitrogen in a type of anaerobic respiration. As this process reduces nitrate levels in soil it is called denitrification. *Pseudomonas denitrificans* is an example of a bacterium that carries out denitrification. Nitrate is broken down when it is used as a terminal electron acceptor in respiration instead of oxygen. Anaerobic soils therefore encourage denitrification. Bad drainage and waterlogging are a frequent cause of anaerobic conditions in soils.

The nitrogen cycle



CHEMOAUTOTROPHY AND THE NITROGEN CYCLE

A chemoautotroph is an organism that obtains energy by oxidizing inorganic compounds and uses it to synthesize ATP. Some of the ATP is used to make organic compounds from carbon dioxide and other inorganic compounds. Chemoautotrophy is only found in bacteria. There are many different types of chemoautotrophic bacteria, including nitrifying bacteria. Nitrifying bacteria obtain the energy for synthesizing ATP by oxidizing ammonia or nitrite. They fix carbon and synthesize sugars and other carbon compounds using the Calvin cycle, as in plants.

THE NITROGEN CYCLE AND SOIL FERTILITY

Farmers and gardeners can increase the growth of plants by applying nitrogen fertilizers such as ammonium nitrate. Promoting the natural processes of the nitrogen cycle can produce the same effect. Ploughing or digging increases the aeration of the soils and therefore encourages nitrification and discourages denitrification. Crop rotation can increase the nitrogen content of soils if a legume is included in the rotation. Legumes develop root nodules in which nitrogen-fixing *Rhizobium* bacteria thrive. When the remains of the crop after harvest are ploughed or dug into the soil, nitrogen fixed by *Rhizobium* is released.

OZONE AND ULTRA-VIOLET RADIATION

At low altitudes in the atmosphere, the concentration of ozone is usually about 0.01 ppm, but at 20 – 50 km above the Earth's surface, in the stratosphere, ozone is much more concentrated – about 1–10 ppm. This is called the ozone layer. Ozone absorbs short wave radiation, especially ultra-violet. The amount of ultra violet radiation reaching the Earth's surface is greatly reduced by the ozone layer. Ultra-violet radiation has very damaging effects on living organisms.

- It increases mutation rates, by causing damage to DNA.
- It can cause cancers, especially of the skin.
- It causes severe sunburn and cataracts of the eye.
- It reduces photosynthesis rates in plants and algae and so affects food chains.

OZONE DEPLETION

Measurements of ozone concentrations in the stratosphere have shown that there has been depletion throughout the world. Since the 1980s an ozone 'hole' has appeared over the Antarctic every year between September and October, which persists for several months.

CHLORINE AND OZONE DEPLETION

CFCs are the main cause of ozone depletion. They are chemical compounds manufactured by humans and released into the atmosphere. Ultra-violet light causes CFCs to dissociate and release atoms of chlorine. These chlorine atoms are highly reactive and cause complex reactions in which ozone is converted to oxygen. The reactions form a cycle, with the chlorine atoms being released again, so that they can go on to cause the destruction of more ozone. One chlorine atom can potentially cause the destruction of hundreds of thousands of ozone molecules.

FIGHTING OZONE DEPLETION

CFCs were used very widely in the 1970s and 1980s:

- in refrigerators as the refrigerant
- in aerosol cans as the propellant
- in gas-blown plastics used for fast-food packaging.

In 1987, after research had shown that CFCs damage the ozone layer, an international treaty called the Montreal Protocol was signed. This treaty set targets for the replacement of CFCs with other chemicals that do not damage the ozone layer. Another measure that has been introduced widely is the collection of CFCs from obsolete refrigerators, to prevent them escaping into the atmosphere. Although levels of CFCs are continuing to rise, they should start to fall by 2010. CFCs are stable chemicals and so levels will only fall slowly, but forecasts made using computers suggest that by 2050 ozone holes over the poles will no longer form.

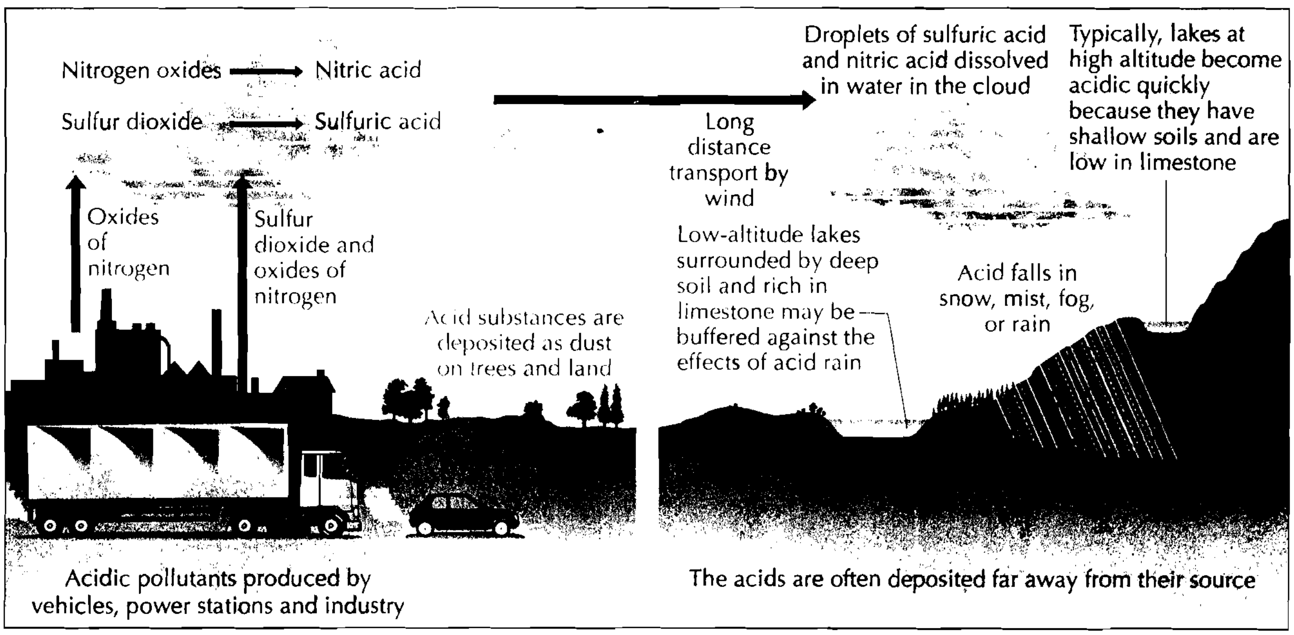
ACID PRECIPITATION

Carbon dioxide dissolves in droplets of water in clouds and makes the precipitation that falls from the clouds slightly acidic. Sulfur dioxide and nitrogen oxides have the same effect, but can make the precipitation much more acidic – as low as pH3. Although there are some natural sources of these gases, human activities are the main source. The figure below shows the origins of these acid pollutants and the processes involved in the formation of acid precipitation.

Sulfur dioxide emissions have been reduced in many countries, but acidification continues to be a problem where levels of nitrogen oxides are still increasing.

THE BIOLOGICAL CONSEQUENCES OF ACID PRECIPITATION

1. Aluminium becomes water soluble in acidified soils and leaches into streams and lakes. Aluminium ions are toxic to fish and in many acidified lakes and rivers all fish have been killed.
2. When soils become acidified, potassium (K^+), magnesium (Mg^{2+}) and calcium ions (Ca^{2+}) leach out, making the soil less fertile and reducing plant growth.
3. Trees affected by acid precipitation show premature leaf fall and dieback of branches. Conifers seem to be particularly vulnerable, perhaps because acid mist condenses on their needles in winter.



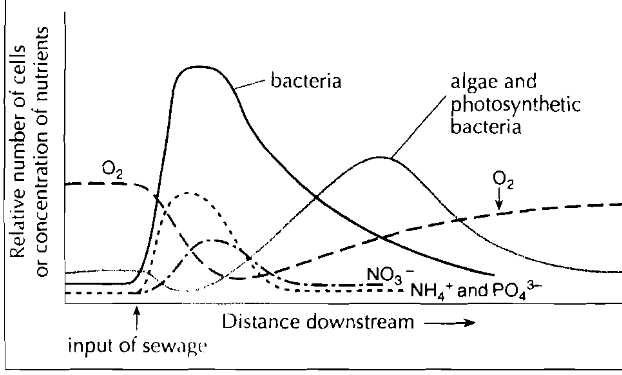
Eutrophication and biological fuels

EFFECTS OF RAW SEWAGE ON RIVERS

Raw sewage and other forms of pollution that are rich in organic matter have profound effects on river ecosystems. The effects can be studied by measuring biotic and abiotic variables at different distances below the sewage input (right).

1. Bacteria consume the organic matter and proliferate.
2. The bacteria use oxygen in aerobic cell respiration. As the numbers of bacteria rise, they consume more and more oxygen, so the **biochemical oxygen demand** of the river water increases. The aeration of the water does not increase, so the water becomes **deoxygenated**. Fish and other animals that depend on dissolved oxygen are sometimes killed.
3. Digestion of organic matter by bacteria causes release of ammonia and phosphate. The ammonia is converted to nitrate by nitrifying bacteria. The increase in levels of nitrate, phosphate and other mineral nutrients is called **eutrophication**.
4. Eutrophication causes proliferation of algae and photosynthetic bacteria (formerly known as blue-green algae). If the numbers of algae are high enough they cause a discolouration of the water, called an **algal bloom**. The algae absorb nutrients from the water, reducing concentrations in the water.
5. The algae release oxygen by photosynthesis, so the water becomes reoxygenated.
6. Primary consumers feed on the algae, reducing their numbers. Conditions in the river are then similar to those before the sewage input – the river has recovered.

Effects of sewage discharge into a river



EFFECTS OF NITRATE FERTILIZER ON RIVERS

Nitrates can also have profound effects on rivers.

1. Nitrate ions are very soluble and are leached from soils very easily if excessive amounts are applied to crops. If phosphate and other minerals also reach a high concentration, a river becomes eutrophic.
2. As with eutrophication caused by sewage pollution, algae proliferate and **algal blooms** develop. Nitrate from fertilisers sometimes cause such excessive growth of algae that some of the algae are deprived of light and die.
3. Bacteria decompose the dead algae. The bacteria create an increased **biochemical oxygen demand** and **deoxygenation** of the water.
4. Low oxygen levels kill fish and other aquatic animals.

BIOLOGICAL FUELS

Biomass already provides large amounts of fuel, in the form of wood, crop residues and dried manure. Methods now exist for converting biomass into fuels that are more convenient to use, such as ethanol and methane.

METHANE GENERATION

Methane is sometimes called marsh gas, because it is naturally produced in anaerobic conditions by methanogenic bacteria. These conditions are recreated in bioreactors used for methane generation (below). Any organic waste can be the raw material, but sewage and manure or slurry from farms are most commonly used. The raw material is loaded into the bioreactor where anaerobic conditions encourage the growth of three groups of naturally occurring bacteria.

The first groups convert organic matter into organic acids and alcohol.

The second group convert organic acids and alcohol into carbon dioxide, hydrogen and acetate.

The third group of bacteria are the methanogens –they produce methane from carbon dioxide, hydrogen and acetate.

Carbon dioxide + hydrogen → methane + water

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Acetate → methane + carbon dioxide

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Methanobacterium and Methanococcus are examples of methanogens.

The gas that is produced in bioreactors is sometimes called biogas and is 40–70% methane. It can be used as a fuel for cooking or lighting. If it is compressed in cylinders it can be used as a fuel in vehicles. It is renewable and non-polluting. Production of it helps to dispose of potentially polluting wastes. The organic matter left over at the end of methane generation can be used as an organic fertilizer, rich in mineral nutrients.

A bioreactor