The Concept of the Ecosystem

An **ecosystem** includes all the living organisms that interact with one another and also with the physical and non-physical factors present.

The boundaries of the ecosystem studied are dictated by the individual carrying out the study. It may be as large as the biosphere or as small as an enclosed bacterial colony.

Understanding ecological terms

The following are important terms which are frequently used in ecology...

Habitat: The place where an organism lives.

Population: A group of organisms, all of the same species, and all of whom live together in a particular habitat.

Community: The total of all populations living together in a particular habitat.

Niche: The position occupied by an organism in a particular ecosystem, dependent upon the resources it uses. The more resources that are taken into account then the more carefully defined the organism's niche will be, the organism will become more specialised.

Ecosystem: The biotic community together with the abiotic environment.

Biotic and abiotic factors

In order to study an ecosystem it is essential that the way in which organisms interact with each other within the ecosystem is considered. These relationships are the **biotic factors** of the ecosystem.

It is also essential that the effects of the physical or non-living factors are considered. These are the **abiotic factors**.

Biotic factors:

The biotic factors affecting an ecosystem are mainly concerned with competition either within a single population or between the members of different populations.

Abiotic factors:

These are the physical factors that affect an ecosystem. **They include the following:**

Light: Many plants are directly affected by light availability since light is required for successful photosynthesis. Plants develop strategies in order to cope with different amounts of available light. They may have larger leaves; develop photosynthetic pigments that require less light; reproduce when light availability is at an optimum.

Temperature: The major effect of temperature is on the enzymes controlling metabolic reactions. As a rule plants will develop more rapidly in warmer temperatures, as will ectothermic animals. It is partly due to temperature that migrations occur.

Water availability: This is mainly a problem in terrestrial ecosystems and does not affect aquatic ecosystems.

In most populations a lack of water leads to water stress which, if severe will lead to death. There are some organisms (e.g, cacti and camels), which have developed successful strategies to cope with water stress.

Oxygen availability: This may be a limiting factor in soil or water. In aquatic ecosystems it is better to have fast flowing cold water as it holds a higher concentration of oxygen.

If water becomes too warm, or the flow rate is too slow there may be a drop in oxygen concentration leading to suffocation for many aquatic organisms.

A similar situation occurs in waterlogged soil where the air spaces between the soil particles are filled with water, reducing the available oxygen for any plants.

Edaphic factors: This term covers any factors referring to soil. There are three main soil types, **clay**, **loam** and **sand**. The different soil types have different particle sizes, this will have an effect on the organisms that are able to survive in them.

Clay soil has fine particles, is easily waterlogged and forms clumps when wet.

Loam soil has particles of different sizes, retains water and does not become waterlogged.

Sandy soil has coarse, well separated particles which allow free draining. They do not retain water well and are easily eroded by wind and water.

Succession

Succession is the process by which communities colonise an ecosystem and are then replaced over time by other communities:

Pioneer species to climax communities

Pioneer species: These are the first species to occupy a new habitat, starting new communities. They have rapid reproductive strategies, enabling them to quickly occupy an uninhabited area. Many have an asexual stage to their reproduction.

Seres: These are the various stages that follow on from the pioneer species.

Climax community: This is the stable community that is reached, beyond which, no further succession occurs.

Types of succession

Primary succession

This occurs when the starting point is a bare ecosystem, (e.g, following a volcanic eruption or a landslide). The pioneer species are usually lichen, moss or algae. They are able to penetrate the bare surface, trap organic material and begin to form humus.

Over several generations soil begins to form. The soil can be used by a more diverse range of plants with deeper root systems. Gradually larger and larger plants occupy the ecosystem along with a diversity of animals.

Finally a climax community is reached and the species present do not change unless the environment changes in some way.

An example of primary succession forming an oak woodland:

1. Bare rock is colonised by mosses and lichen.
2. Small plants, ferns and grasses take over.
3. Larger plants with deeper roots appear.
4. Bushes and shrubs replace non-woody plants.
5. Fast growing trees form a dense, low wood.
6. Larger, slow growing oak trees create the oak woodland.

Secondary succession

This occurs when the starting point is bare, existing soil, (e.g, following a fire, flood or human intervention). This type of succession proceeds in the same way as primary succession except that the pioneer species tend to be grasses and fast growing plants.

An example of secondary succession forming an oak woodland:

1. Bare soil is colonised by grasses and pioneer plants.
2. Grasses begin to predominate with time.
3. Shrubs replace the grasses.
4. Fast growing trees appear.
5. Slow growing oaks create the climax community.

Populations

The factors affecting population growth, and how populations increase in numbers are important concepts in ecology as they are necessary in order to successfully study how ecosystems work.

Changes in populations over time

The number of individuals per unit area of chosen habitat is known as the **population density. The population density can be affected by a number of factors:**

1. **Birth:** The number of new individuals born to a population.
2. **Immigration:** The number of new individuals joining a population.

   Both of these factors will serve to increase the population density.

3. **Death:** The number of individuals within a population that die.
4. **Emigration:** The number of individuals leaving a population.

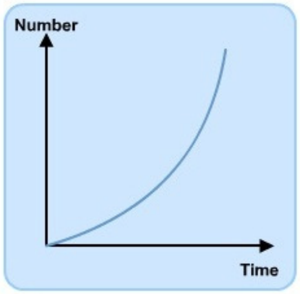
Both of these factors will serve to **decrease** the population density.

Population size can also be affected by the following:

Density dependent factors: These are any factors, dependent on the density of the population in question. Some examples of these are predation, disease and competition.

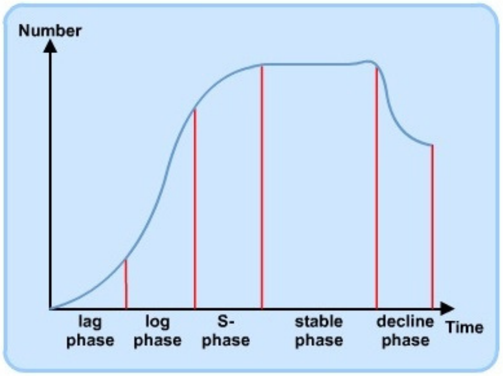
Density independent factors: These are any factors, not dependent upon the density of the population in question. Some examples of these are climate and catastrophe.

Population changes can be studied using population graphs:



This is an **exponential growth curve.** This type of curve occurs when a population grows in size under ideal conditions. The population will double in size during a constant period of time. This type of population growth is theoretically possible but is rarely seen in nature. The closest to an exponential growth curve is that of some bacterial colonies which are able to double their numbers with each reproduction, (e.g, 2-4-8-16-32-64-128-256-etc).

Normally populations will be prevented from undergoing uncontrolled exponential growth by **limiting factors.** Most populations will adhere to a **sigmoid growth curve.**



The phases that make up a sigmoid growth curve are as follows:

Lag phase: Population growth begins slowly from a few individuals.

Log phase: Exponential growth occurs, the conditions are ideal and maximum growth rate is reached.

S-phase: Growth rate begins to slow down as factors such as food, water and space become limiting.

Stable phase: Carrying capacity for the population has been reached and the population number becomes stable. The carrying capacity is the population size that can be supported by a particular environment.

Decline phase: If there is a sudden change in the environment meaning that the environment can no longer support the population, such as a drought causing food shortage, the population will crash and the whole process begins again.

Competition

Competition is often considered to be the most important biotic factor controlling population density.

Competition between organisms may be for a number of different factors, including food, light, territory or reproductive partners.

Intraspecific competition:

This is competition for a resource between individuals from the **same population.** It causes the population growth rate to slow down, and has a greater effect the less plentiful the resource is.

This form of competition can also be categorised as **scramble** or **contest.**

Scramble competition:

This occurs when many members of a population compete for a scarce resource, and each member gains a portion of that resource. This is often seen when populations compete for a food source and each member of the population gains some of that food source.

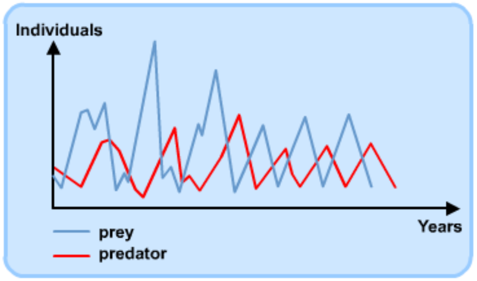
Contest competition:

This occurs when two or more members of a population compete for a resource but only one member of the population gains that resource. This can be seen when competing for mates or territory for example.

Interspecific competition:

This is competition for a resource between members of different populations in the same community. It will result in the competing populations increasing in size more slowly than normal. This type of competition may result in the extinction of one of the competing populations.

Examples of interspecific reproduction are predator - prey relationships and competition for resources.



In this situation it appears that as the prey population crashes, it is followed by a crash in the predator population due to a reduction in food. Consequently the prey population will then increase since the predation pressure is reduced, this is closely followed by a rise in predator numbers.

The explanation to this appears to be straightforward, however it is not as simple at it at first appears since the individual populations have been shown to follow these patterns independently of one another.

Energy Flow and Nutrient Cycles

Trophic levels

This describes a specific level in a food chain. The term ***trophic*** refers to **nutrition**.

There are four important levels in most food chains:

Producers: Organisms which convert some of the energy from the sun into stored chemical energy (usually plants). ***Primary consumers:*** Organisms that obtain energy by consuming producers. They are herbivores. ***Secondary consumers:*** Organisms which obtain energy by consuming primary consumers. They are carnivores. ***Decomposers:*** These organisms form the end point of every food chain. They are bacteria or fungi that obtain their energy by breaking down dead organisms from the other trophic levels.

Each description of a trophic level will describe an organisms role in the ecosystem. Organisms may occupy more than one trophic level, (e.g. when acting as omnivores).

Transfer of energy between trophic levels

Transfer of energy between trophic levels is relatively inefficient. Energy is transferred from one trophic level to another as organisms are consumed.

In **primary producers** the main energy input is from the solar energy. In a plant, not all of the solar energy available actually makes it into the leaf.

There is loss of energy by **reflection** from the leaf, **transmission** through the leaf, and because some of the energy is the **incorrect wavelength**.

The energy that is taken up by the producer is then **fixed** by photosynthesis, although again a proportion of this energy is lost as it is used up during photosynthetic reactions.

Of the energy that is fixed in photosynthesis some will be used during **respiration** whilst the remaining energy is the portion that is incorporated into the **biomass**. It is the energy that is incorporated into the biomass that is available for the next trophic level.

In the consumer a further series of energy losses occur. The consumer will take in a certain amount of energy from the trophic level beneath it.

This energy intake does not equal the amount of energy available in the biomass of this organism since feeding is an inefficient process. There will be a loss of energy through the production of urine and faeces, as well as losses through respiration and heat loss. This leaves a proportion of the energy consumed to be incorporated into the biomass.

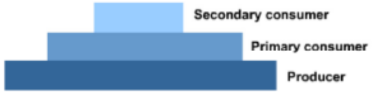
It is generally accepted that only around 10% of the energy gained from the previous trophic level is passed on to the next level. All other energy is lost as described above. This limits the number of trophic levels in any food chain.

Pyramids in ecology

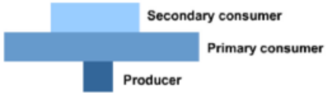
Ecological pyramids are used as a tool to illustrate the feeding relationships of the organisms, which together make up a community.

Pyramid of numbers

This is the simplest way of illustrating the feeding relationships within a community. The commonest form shows that the numbers of organisms occupying each trophic level decreases from producers to secondary consumers and beyond.



Two problems with this form of pyramid are that the numbers involved may be huge (in the hundreds of thousands) and some pyramids may be **inverted.**

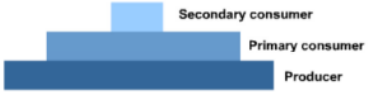


Pyramid of biomass

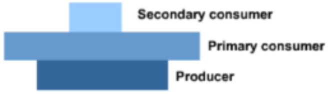
This indicates the feeding relationship between organisms occupying different trophic levels with reference to their biomass.

Biomass can be measured as either wet mass or dry mass. Measuring the dry mass is more accurate as it does not include the variable water content of organisms.

The commonest form of the pyramid of biomass shows that the total biomass of organisms occupying each trophic level decreases from producers to secondary consumers and beyond.

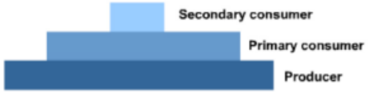


There is still the problem that a pyramid of biomass can be inverted and also it does not take account of changes over time. The sampling must all be carried out at one moment in time and therefore indicates the **standing crop** and not the **productivity**.



Pyramid of energy

This is the most accurate representation of the feeding relationship between the organisms at different trophic levels. It takes into account the energy gains and losses over a period of time.



These consider how inorganic nutrients cycle through the various trophic levels and remain constantly available.

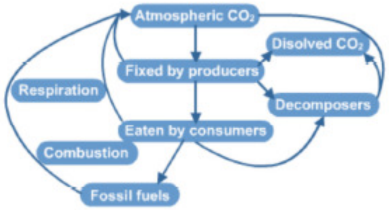
The carbon cycle

Carbon dioxide in the atmosphere and dissolved carbon dioxide in the oceans provide the major source of **abiotic carbon** for organisms.

The carbon is **fixed** from the carbon dioxide by photosynthesis to form **organic compounds** such as carbohydrates, proteins and lipids in producers.

The fixed carbon dioxide is then taken up by primary consumers and passed on to secondary consumers and beyond.

Carbon can be returned to its abiotic source via **respiration**, **combustion** of fossil fuels, and death and decay by **decomposers**.



The nitrogen cycle

The **abiotic source** of nitrogen is atmospheric nitrogen gas.

Nitrogen fixing bacteria convert atmospheric nitrogen to nitrates in the soil via **ammonia** and **nitrites**.

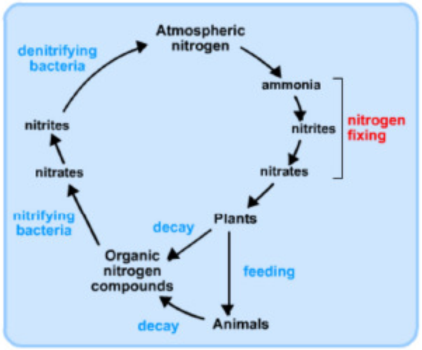
Nitrates can be absorbed from the soil by plants, which convert the nitrates and incorporate the nitrogen into **organic nitrogen compounds**.

The organic nitrogen compounds are passed on to other trophic levels through **feeding**.

Death and decay of plants and animals returns the nitrogen to the soil as organic nitrogen compounds.

Nitrifying bacteria will produce nitrates from these organic nitrogen compounds.

Denitrifying bacteria are able to return nitrogen to its abiotic source by converting nitrates to nitrogen gas.



Human Effects on the Environment

As humans occupy every continent, we have changed the environment around us in countless ways. Many changes have been beneficial and many have been adverse, here we discuss deforestation as we can see directly many of the effects widespread deforestation has had on ecosystems.

Deforestation

Deforestation is the rapid destruction of woodland. Although it can occur due to natural catastrophe it is most commonly caused by human intervention.

Deforestation has been occurring since humans have been able to cut down trees, but it has increased greatly over the last century.

The major reasons for deforestation are:

- Obtaining hardwood (e.g, teak) for furniture.
- Obtaining softwood for paper and other wood products.
- Clearing areas for cattle farming.
- Clearing areas for agriculture.
- Clearing areas for urbanisation, including road building.

Some effects of deforestation are:

- Changes in nutrient cycles.
- Less carbon dioxide is removed from the atmosphere by photosynthesis, leading to a rise in atmospheric carbon dioxide concentration.
- Less oxygen is released into the atmosphere as less photosynthesis occurs.
- Fewer trees means less transpiration, which may lead to a less humid atmosphere since less water evaporates from soil than from leaves.

Climatic changes

With a drier atmosphere there are knock on effects to the water cycle resulting in less rainfall.

With fewer trees to protect the soil there is a more rapid heating of the soil. This can lead to thermal gradients occurring resulting in an increase in wind intensity and frequency.

Reduced soil fertility

Removal of trees, particularly deciduous ones, removes the major source of nutrients for the soil. There may be as much as a 90% loss of nutrients through deforestation.

There is likely to be an increase in soil erosion as the bare soil is exposed directly to wind and rain and there are no trees roots to stabilise the soil structure.

Flooding and landslide

Under normal conditions most of the rain falling on woodland is absorbed either through the leaves or the roots. If the trees are removed the water accumulates in the soil, increasing instability and resulting in possible landslips.

As the rain water is not being absorbed, it can run off the area into adjacent rivers and lead to flooding.

Destruction of species

Many species are endemic to forested areas. If large areas of forest are lost they will be unable to move from one area to another, this will result in isolated populations, which may lead to a decrease in genetic diversity. There are many medically useful plants in forest habitats, these will be lost due to deforestation. There are many undiscovered species, particularly plants and insects that may have uses for humans.

Due to deforestation, these possible uses may never be discovered.

Ecosystems & Human Influence

Ecosystems

Ecology is the study of inter-relationships between organisms and their environment. Its aim it to explain why organisms live where they do. To do this ecologists study ecosystems, areas that can vary in size from a pond to the whole planet.

Ecosystem	A reasonably self-contained area together with all its living organisms.
Habitat	The physical or abiotic part of an ecosystem, i.e. a defined area with specific characteristics where the organisms live, e.g. oak forest, deep sea, sand dune, rocky shore, moorland, hedgerow, garden pond, etc.
Community	The living or biotic part of an ecosystem, i.e. all the organisms of all the different species living in one habitat.
Biotic	Any living or biological factor.
Abiotic	Any non-living or physical factor.
Population	The members of the same species living in one habitat.
Species	A group of organisms that can successfully interbreed

Estimating Populations and Distribution

To study the dynamics of a population, or how the distribution of the members of a population is influenced by a biotic or an abiotic factor, it is necessary to estimate the population size. In other words, it will be necessary to count the number of individuals in a population. Such counting is usually carried out by taking samples.

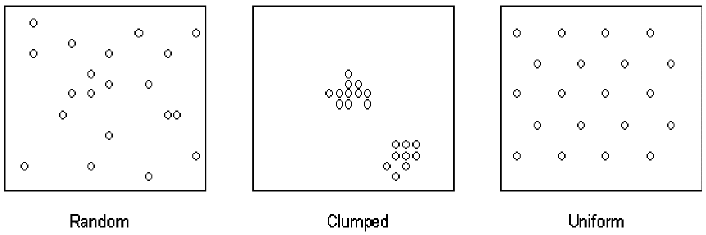
One of the most fundamental problems faced by community and population ecologists is that of measuring population sizes and distributions. The data is important for comparing differences between communities and species. It is necessary for impact assessments (measuring effects of disturbance) and restoration ecology (restoring ecological systems). It is also used to set harvest limits on commercial and game species (e.g. fish, deer, etc.).

In most cases it is either difficult or simply not possible to census all of the individuals in the target area. The only way around this problem is to estimate population size using some form of sampling technique. There are numerous types of sampling techniques. Some are designed for specific types of organisms (e.g. plants vs. mobile animals). As well there are numerous ways of arriving at estimates from each sampling technique. All of these procedures have advantages and disadvantages. In general, the accuracy of an estimate depends on 1) the number of samples taken, 2) the method of collecting the samples, 3) the proportion of the total population sampled.

Sampling is viewed by statistical ecologists as a science in its own right. In most cases, the object is to collect as many randomly selected samples as possible (so as to increase the proportion of the total population sampled). The accuracy of an estimate increases with the number of samples taken. This is because the number of individuals found in any given sample will vary from the number found in other samples. By collecting numerous samples, the effect of these variations can be averaged out. The purpose for collecting the samples randomly is to avoid biasing the data. Data can become biased when individuals of some species are sampled more frequently, or less frequently, than expected at random. Such biases can cause the population size to be either over estimated or under estimated, and can lead to erroneous estimates of population size.

Population size generally refers to the number of individuals present in the population, and is self-explanatory. Density refers to the number of individuals in a given area. For ecologists density is usually a more useful measure. This is because density is standardized per unit area, and therefore, can be correlated with environmental factors or used to compare different populations.

The spatial distribution of a population is a much more complicated matter. Basically, there are three possible types of spatial distributions (dispersions) (see diagrams below). In a random dispersion, the locations of all individuals are independent of each other. In a uniform dispersion, the occurrence of one individual reduces the likelihood of finding another individual nearby. In this case the individuals tend to be spread out as far from each other as possible. In a clumped dispersion, the occurrence of one individual increases the likelihood of finding another individual nearby. In this case, individuals tend to form groups (or clumps).



Ecologists are often interested in the spatial distribution of populations because it provides information about the social behaviour and/or ecological requirements of the species. For example, some plants occur in clumped distributions because they propagate by rhizomes (underground shoots) or because seed dispersal is limited. Clumped distributions in plants may also occur because of slight variations in soil chemistry or moisture content. Many animals exhibit rather uniform distributions because they are territorial (especially birds), expelling all intruders from their territories. Random distributions are also common, but their precise cause is more difficult to explain.

Unfortunately, it is often difficult to visually assess the precise spatial distribution of a population. Furthermore, it is often useful to obtain some number (quantitative measure) that describes spatial distribution in order to compare different populations. For this reason, there are a variety of statistical procedures that are used to describe spatial distributions.

Communities are assemblages of many species living in a common environment. Interactions between species can have profound influences of their distributions and abundances. Comprehensive understanding of how species interact can contribute to understanding how the community is organized. One way to look at species interactions is to evaluate the level of association between them. Two species are said to be positively associated if they are found together more often than expected by chance. Positive associations can be expected if the species share similar microhabitat needs or if the association provides some benefit to one (commensualisms) or both (mutualism) of the species involved. Two species are negatively associated if they are found together less frequently than expected by chance. Such a situation can arise if the species have very different microhabitat requirements, or if one species, in some way, inhibits the other. For example, some plants practice allelopathy, the production and release of chemicals that inhibit the growth of other plant species. Allelopathy results in a negative association between the allelopathic species and those species whose growth is inhibited.

Random sampling with quadrats

The quadrat method is used primarily in studies of plant populations, or where animals are immobile. The principal assumptions of this technique are that the quadrats are chosen randomly, the organisms do not move from one quadrat to another during the census period, and that the samples taken are representative of the population as a whole. It is often conducted by dividing the census area into a grid. Each square within the grid is known as a quadrat and represents the sample unit. Quadrats are chosen at random by using a random number generator or a random number table to select coordinates. The number of individuals of the target species is then counted in each of the chosen quadrats.

Ecologists use units to measure organisms within the quadrats. Frequency (f) is an indication of the presence of an organism in a quadrat area. This gives no measure of numbers, however the usual unit is that of density – the numbers of the organisms per unit area. Sometimes percentage cover is used, an indication of how much the quadrat area is occupied.

Counting along Transects

Transects are used to describe the distribution of species in a straight line across a habitat. Transects are particularly useful for identifying and describing where there is a change in habitat. A simple line transect records all of the species which actually touch the rope or tape stretched across the habitat. A belt transect records all the species present between two lines, and an interrupted belt transect records all those species present in a number of quadrats places at fixed points along a line stretched across the habitat.

Mark-release-recapture techniques for more mobile species

This method of sampling is most useful when dealing with an animal population that moves around. Ecologists must always ensure minimum disturbance of the organism if results are to be truly representative and that the population will behave as normal. In this method individual organisms are captured, unharmed, using a quantitative technique. They are counted and then discretely marked or tagged in some way, and then released back into the environment. After leaving time for dispersal, the population is then recaptured, and another count is made. This gives the number of marked animals and the number unmarked. This can allow ecologists to estimate of the entire population in a given habitat.

The following equation is used to estimate the population:

$$\mathbf{S = \frac{S_1 \times S_2}{S_3}}$$

S = total number of individuals in the total population

S_1= number captured, marked and released in first sample e.g. 8

S_2= total number captured in second sample e.g. 8

S_3= total marked individuals captured in second sample e.g. 2

$$S = \frac{8 \times 10}{2}$$

population = 40 individuals

Diversity

Diversity depends on the number of species (species richness of a community) in an ecosystem and the abundance of each species – the number of individuals of each species. The populations of an ecosystem can support demands on abiotic and biotic factors. The growth of populations depends on limiting factors:

- Abiotic factors
  - physiological adaptations of organisms only allow them to live in a certain range of pH, light, temp etc – it is part of what defines their niche.
- Biotic factors (interactions between organisms)
  - Intraspecific competition occurs between individuals of the same species eg for a patch of soil to grow on, or a nesting site or food.

- Interspecific competition occurs between different species needing the same resource – at the same trophic level.
- Plant species compete for light, herbivore species compete for plants or carnivore species compete for prey
- Predation – a predator is a limiting factor on growth on the population of its prey and the prey is a limiting factor on the predator population

An index of diversity is used as a measure of the range and numbers of species in an area. It usually takes into account the number of species present and the number of individuals of each species. It can be calculated by the following formulae:

$$\mathbf{d} = \frac{\mathbf{N(N-1)}}{\mathbf{\Sigma n(n-1)}}$$

Where:
N = total number of organisms of all species in the area
d = index of diversity
n = total number of organisms of each species in the area

e.g.

crested newt	8
stickleback	20
Leech	15
Great pond snail	20
Dragon fly larva	2
Stonefly larva	10
Water boatman	6
Caddisfly larva	30
N =	**111**

$$d = \frac{111 \text{ X } 110}{(8\text{X}7) + (20\text{X}19) + (15\text{X}14) + (20\text{X}19) + (2\text{X}1) + (10\text{X}9) + (6\text{X}5) + (30\text{X}29)}$$

$$d = \frac{12210}{2018}$$ therefore **d = 6.05**

In another pond there were:

crested newt	45	d = 2.6 Comparing both indices, 6.05 is an indicator of greater diversity. The higher number indicates greater diversity
stickleback	4	
Leech	18	
Great pond snail	10	

In extreme environments the diversity of organisms is usually low (has a low index number). This may result in an unstable ecosystem in which populations are usually dominated by abiotic factors. The abiotic factor(s) are extreme and few species have adaptations allowing them to survive. Therefore food webs are relatively simple, with few food chains, or connections between them – because few producers survive. This can produce an unstable ecosystem because a change in the population of one species can cause big changes in populations of other species.

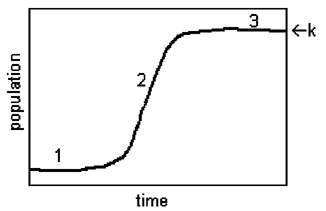
In less hostile environments the diversity of organisms is usually high (high index number). This may result in a stable ecosystem in which populations are usually dominated by biotic factors, and abiotic factors are not extreme. Many species have adaptations that allow them to survive, including many plants/producers. Therefore food webs are complex, with many inter-connected food chains. This results in a stable ecosystem because if the population of one species changes, there are alternative food sources for populations of other species.

Population Ecology

Population Ecology is concerned with the question: why is a population the size it is? This means understanding the various factors that affect the population.

Population Growth

When a species is introduced into a new environment its population grows in a characteristic way. This growth curve is often seen experimentally, for example bees in a hive, sheep in Tasmania, bacteria in culture. The curve is called a logistic or sigmoid growth curve.



The growth curve has three phases, with different factors being responsible for the shape of each phase. The actual factors depend on the ecosystem, and this can be illustrated by considering two contrasting examples: yeast in a flask (reproducing asexually), and rabbits in a field (reproducing sexually).

	Yeast in a flask	Rabbits in a field
1. Lag phase	Little growth while yeast starts transcribing genes and synthesising appropriate enzymes for new conditions.	Little growth due to small population. Individuals may rarely meet, so few matings. Long gestation so few births.
2. Rapid Growth Phase	Rapid exponential growth. No limiting factors since relatively low density.	Rapid growth, though not exponential. Few limiting factors since relatively low density.
3. Stable Phase	Slow growth due to accumulation of toxic waste products (e.g. ethanol) or lack of sugar.	Slow growth due to intraspecific competition for food/territory, predation, etc.

At the end of phase 3 the population is stable. This population is called the carrying capacity of the environment (K), and is the maximum population supported by a particular ecosystem.

Factors Affecting Population Size

Many different factors interact to determine population size, and it can be very difficult to determine which factors are the most important. Factors can be split into two broad group: abiotic factors and biotic factors. We'll look at 7 different factors.

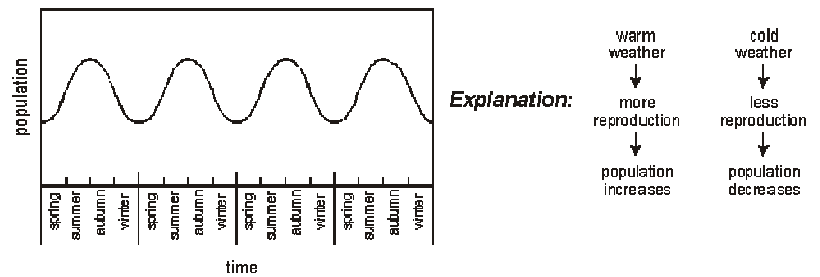
1. Abiotic Factors

The population is obviously affected by the abiotic environment such as: temperature; water/humidity; pH; light/shade; soil (edaphic factors); mineral supply; current (wind/water); topography (altitude, slope, aspect); catastrophes (floods/fire/frost); pollution. Successful species are generally well adapted to their abiotic environment.

In harsh environments (very cold, very hot, very dry, very acid, etc.) only a few species will have successfully adapted to the conditions so they will not have much competition from other species, but in mild environments lots of different species could live there, so there will be competition. In other words in harsh environments abiotic factors govern who survives, while in mild environments biotic factors (such as competition) govern who survives.

2. Seasons

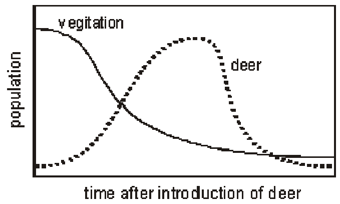
Many abiotic factors vary with the seasons, and this can cause a periodic oscillation in the population size.



This is only seen in species with a short life cycle compared to the seasons, such as insects. Species with long life cycles (longer than a year) do not change with the seasons like this.

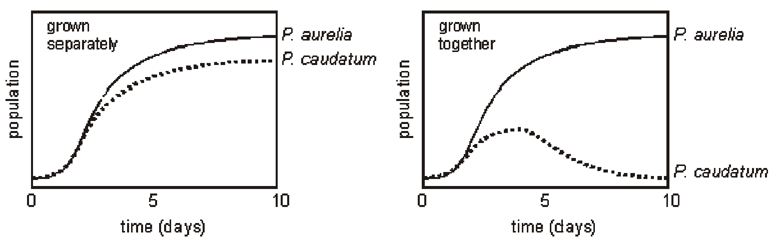
3. Food Supply

A population obviously depends on the population of its food supply: if there is plenty of food the population increases and vice versa. For example red deer introduced to an Alaskan island at first showed a population increase, but this large population grazed the vegetation too quickly for the slow growth to recover, so the food supply dwindled and the deer population crashed.



4. Interspecific Competition

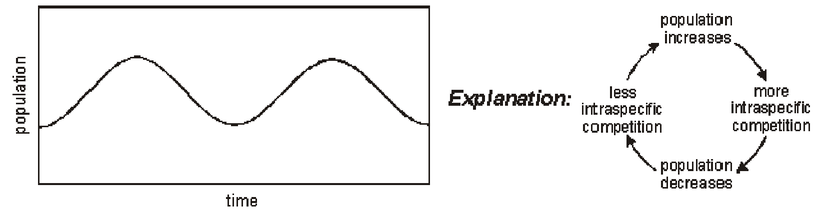
Interspecific competition is competition for resources (such as food, space, water, light, etc.) between members of different species, and in general one species will out-compete another one. This can be demonstrated by growing two different species of the protozoan *Paramecium* in flasks in a lab. They both grow well in lab flasks when grown separately, but when grown together *P.aurelia* out-competes *P.caudatum* for food, so the population of *P.caudatum* falls due to interspecific competition:



5. Intraspecific Competition

Intraspecific competition is competition for resources between members of the same species. This is more significant than interspecific competition, since member of the same species have the same niche and so compete for exactly the same resources.

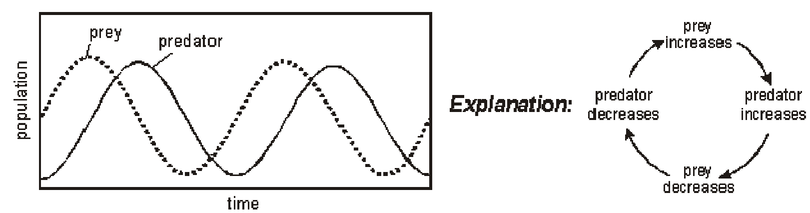
Intraspecific competition tends to have a stabilising influence on population size. If the population gets too big, intraspecific population increases, so the population falls again. If the population gets too small, intraspecific population decreases, so the population increases again:



Intraspecific competition is also the driving force behind natural selection, since the individuals with the "best" genes are more likely to win the competition and pass on their genes. Some species use aggressive behaviour to minimise real competition. Ritual fights, displays, threat postures are used to allow some individuals (the "best") to reproduce and exclude others (the "weakest"). This avoids real fights or shortages, and results in an optimum size for a population.

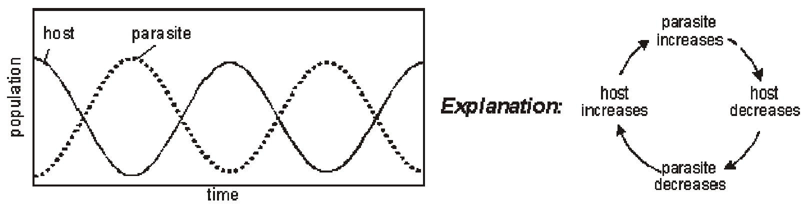
6. Predation

The populations of predators and their prey depend on each other, so they tend to show cyclical changes. This has been famously measured for populations of lynx (predator) and hare (prey) in Canada, and can also be demonstrated in a lab experiment using two species of mite: *Eotetranchus* (a herbivore) and *Typhlodromus* (a predator). If the population of the prey increases, the predator will have more food, so its population will start to increase. This means that more prey will be eaten, so its population will decrease, so causing a cycle in both populations:



7. Parasitism and Disease

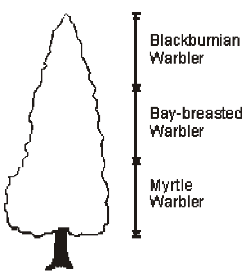
Parasites and their hosts have a close symbiotic relationship, so their populations also oscillate. This is demonstrated by winter moth caterpillars (the host species) and wasp larvae (parasites on the caterpillars). If the population of parasite increases, they kill their hosts, so their population decreases. This means there are fewer hosts for the parasite, so their population decreases. This allows the host population to recover, so the parasite population also recovers:



A similar pattern is seen for pathogens and their hosts.

The Ecological Niche

A population's <u>niche</u> refers to its role in its ecosystem. This usually means its feeding role in the food chain, so a particular population's niche could be a producer, a predator, a parasite, a leaf-eater, etc. A more detailed description of a niche should really include many different aspects such as its food, its habitat, its reproduction method etc, so gerbils are desert seed-eating mammals; seaweed is an inter-tidal autotroph; fungi are asexual soil-living saprophytes. Identifying the different niches in an ecosystem helps us to understand the interactions between populations. Members of the same population always have the same niche, and will be well-adapted to that niche, e.g. nectar feeding birds have long thin beaks.

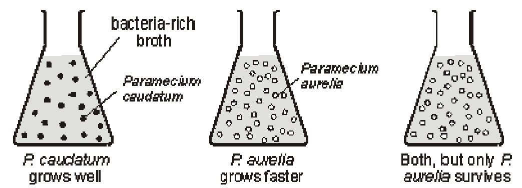


Species with narrow niches are called <u>specialists</u> (e.g. anteater). Many different specialists can coexist in the same habitat because they are not competing, so this can lead to high diversity, for example warblers in a coniferous forest feed on insects found at different heights. Specialists rely on a constant supply of their food, so are generally found in abundant, stable habitats such as the tropics.

Species with broad niches are called <u>generalists</u> (e.g. common crow). Generalists in the same habitat will compete, so there can only be a few, so this can lead to low diversity. Generalists can cope with a changing food supply (such as seasonal changes) since they can switch from one food to another or even one habitat to another (for example by migrating).

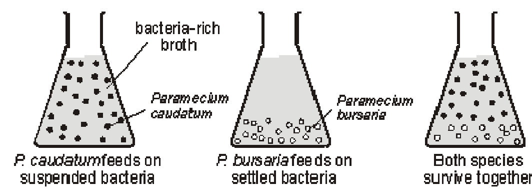
The niche concept was investigated in some classic experiments in the 1930s by <u>Gause</u>. He used flasks of different species of the protozoan *Paramecium*, which eats bacteria.

Experiment. 1:



Conclusion: These two species of *Paramecium* share the same niche, so they compete. *P. aurelia* is faster-growing, so it out-competes *P. caudatum.*

Experiment. 2:



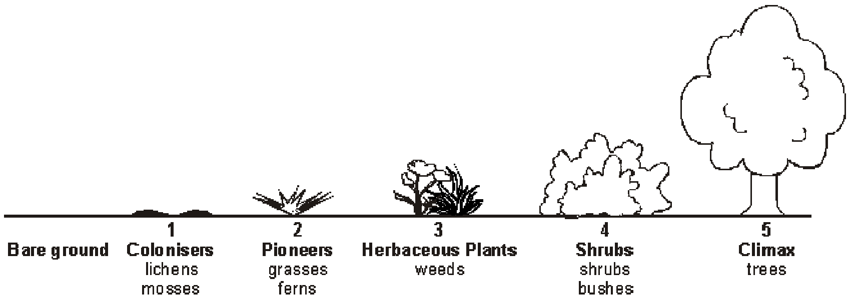
Conclusion: These two species of *Paramecium* have slightly different niches, so they don't compete and can coexist.

It is important to understand the distribution in experiment 2. *P. caudatum* lives in the upper part of the flask because only it is adapted to that niche and it has no competition. In the lower part of the flask both species could survive, but only *P. bursaria* is found because it out-competes *P. caudatum*. If *P. caudatum* was faster-growing it would be found throughout the flask.

The niche concept is summarised in the competitive exclusion principle: Two species cannot coexist in the same habitat if they have the same niche.

Succession

Ecosystems are not fixed, but constantly change with time. This change is called succession. Imagine a lifeless area of bare rock. What will happen to it as time passes?



1. Very few species can live on bare rock since it stores little water and has few available nutrients. The first colonisers are usually lichens, which have a mutualistic relationship between an alga and a fungus. The alga photosynthesises and makes organic compounds, while the fungus absorbs water and minerals and clings to the rock. Lichens are such good colonisers that almost all "bare rock" is actually covered in a thin layer of lichen. Mosses can grow on top of the lichens. Between them, these colonisers start to erode the rock and so form a thin soil. Colonisers are slow growing and tolerant of extreme conditions.

2. Pioneer species such as grasses and ferns grow in the thin soil and their roots accelerate soil formation. They have a larger photosynthetic area, so they grow faster, so they make more detritus, so they form better soil, which holds more water.

3. Herbaceous Plants such as dandelion, goosegrass ("weeds") have small wind-dispersed seeds and rapid growth, so they become established before larger plants.

4. Larger plants (shrubs) such as bramble, gorse, hawthorn, broom and rhododendron can now grow in the good soil. These grow faster and so out-compete the slower-growing pioneers.

5. Trees grow slowly, but eventually shade and out-compete the shrubs, which are replaced by shade-tolerant forest-floor species. A complex food web is now established with many trophic levels and interactions. This is called the climax community.

These stages are called seral stages, or seral communities, and the whole succession is called a sere. Each organism modifies the environment, so creating opportunities for other species. As the succession proceeds the community becomes more diverse, with more complex food webs being supported. The final seral stage is stable (assuming the environment doesn't change), so succession stops at the climax stage. In England the natural climax community is oak or beech woodland (depending on the underlying rock), and in the highlands of Scotland it is pine forests. In Roman times the country was covered in oak and beech woodlands with herbivores such as deer, omnivores such as bear and carnivores such as wolves and lynxes. It was said that a squirrel could travel from coast to coast without touching ground.

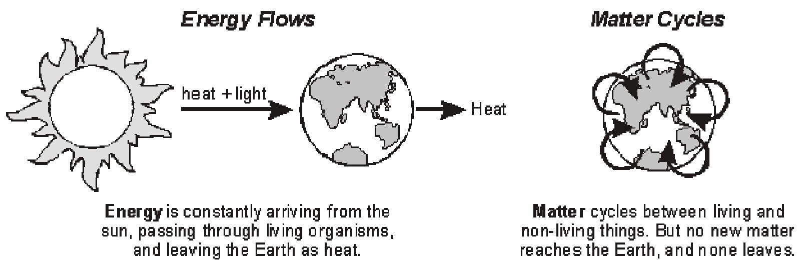
Humans interfere with succession, and have done so since Neolithic times, so in the UK there are few examples of a natural climax left (except perhaps small areas of the Caledonian pine forest in the Scottish Highlands). Common landscapes today like farmland, grassland, moorland and gardens are all maintained at pre-climax stages by constant human interventions, including ploughing, weeding, herbicides, burning, crop planting and grazing animals. These are examples of an artificial climax, or plagioclimax.

- Primary succession starts with bare rock or sand, such as behind a retreating glacier, after a volcanic eruption, following the silting of a shallow lake or seashore, on a new sand dune, or on rock scree from erosion and weathering of a mountain.
- Secondary succession starts with soil, but no (or only a few) species, such as in a forest clearing, following a forest fire, or when soil is deposited by a meandering river.

Energy and Matter

Before studying ecosystems in any further detail, it is important to appreciate the difference between energy and matter. Energy and matter are quite different things and cannot be inter-converted.

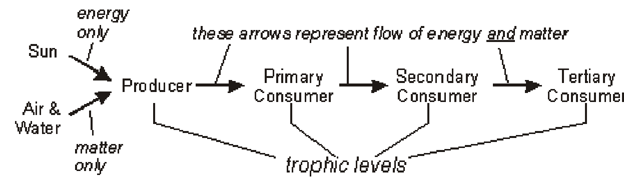
- Energy comes in many different forms (such as heat, light, chemical, potential, kinetic, etc.) which can be inter-converted, but energy can never be created, destroyed or used up. If we talk about energy being "lost", we usually mean as heat, which is radiated out into space. Energy is constantly arriving on earth from the sun, and is constantly leaving the earth as heat, but the total amount of energy on the earth is constant.
- Matter comes in three states (solid, liquid and gas) and again, cannot be created or destroyed. The total amount of matter on the Earth is constant. Matter (and especially the biochemicals found in living organisms) can contain stored chemical energy, so a cow contains biomass (matter) as well as chemical energy stored in its biomass.



All living organisms need energy and matter from their environment. Matter is needed to make new cells (growth) and to create now organisms (reproduction), while energy is needed to drive all the chemical and physical processes of life, such as biosynthesis, active transport and movement.

Food Chains and Webs

The many relationships between the members of a community in an ecosystem can be described by food chains and webs. Each stage in a food chain is called a trophic level, and the arrows represent the flow of energy and matter through the food chain. Food chains always start with photosynthetic producers (plants, algae, plankton and photosynthetic bacteria) because, uniquely, producers are able to extract both energy and matter from the abiotic environment (energy from the sun, and 98% of their matter from carbon dioxide in the air, with the remaining 2% from water and minerals in soil). All other living organisms get both their energy and matter by eating other organisms.



Although this represents a "typical" food chain, with producers being eaten by animal consumers, different organisms use a large range of feeding strategies (other than consuming), leading to a range of different types of food chain. Some of these strategies are defined below, together with other terms associated with food chains.

Producer	An organism that produces food from carbon dioxide and water using photosynthesis. Can be plant, algae, plankton or bacteria.
Consumer	An animal that eats other organisms
Herbivore	A consumer that eats plants (= primary consumer).
Carnivore	A consumer that eats other animals (= secondary consumer).
Top carnivore	A consumer at the top of a food chain with no predators.
Omnivore	A consumer that eats plants or animals.
Vegetarian	A human that chooses not to eat animals (humans are omnivores)
Autotroph	An organism that manufactures its own food (= producer)
Heterotroph	An organism that obtains its energy and mass from other organisms (=consumers + decomposers)
Plankton	Microscopic marine organisms.

Phytoplankton	"Plant plankton" i.e. microscopic marine producers.
Zooplankton	"Animal plankton" i.e. microscopic marine consumers.
Predator	An animal that hunts and kills animals for food.
Prey	An animal that is hunted and killed for food.
Scavenger	An animal that eats dead animals, but doesn't kill them
Detritus	Dead and waste matter that is not eaten by consumers
Carrion	Alternative word for detritus
Decomposer	An organism that consumes detritus (= detrivores + saprophytes)
Detrivore	An animal that eats detritus.
Saprophyte	A microbe (bacterium or fungus) that lives on detritus.
Symbiosis	Organisms living together in a close relationship (= parasitism, mutualism, pathogen).
Mutualism	Two organisms living together for mutual benefit.
Commensalism	Relationship in which only one organism benefits
Parasite	An organism that feeds on a larger living host organism, harming it
Pathogen	A microbe that causes a disease.

So food chains need not end with a consumer, and need not even start with a producer, e.g.:

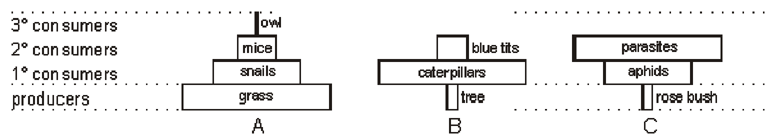
Producer → Primary Consumer → Top Consumer → Scavenger

Ecological Pyramids

In general as you go up a food chain the size of the individuals increases and the number of individuals decreases. These sorts of observations can be displayed in ecological pyramids, which are used to quantify food chains. There are three kinds:

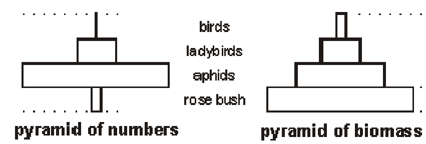
1. Pyramids of Numbers.

These show the numbers of organisms at each trophic level in a food chain. The width of the bars represent the numbers using a linear or logarithmic scale, or the bars may be purely qualitative. The numbers should be normalised for a given area for a terrestrial habitat (usually m^2), or volume for a marine habitat (m^3). Pyramids of numbers are most often triangular (or pyramid) shaped, but can be almost any shape. In the pyramids below, A shows a typical pyramid of numbers for carnivores; B shows the effect of a single large producer such as a tree; and C shows a typical parasite food chain.



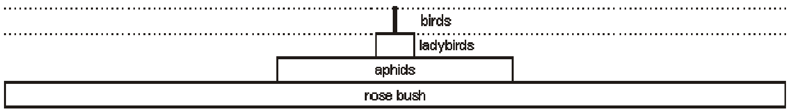
2. Pyramids of Biomass

These convey more information, since they consider the total mass of living organisms (i.e. the biomass) at each trophic level. The biomass should be dry mass (since water stores no energy) and is measured in kg m^{-2}. The biomass may be found by drying and weighing the organisms at each trophic level, or by counting them and multiplying by an average individual mass. Pyramids of biomass are always pyramid shaped, since if a trophic level gains all its mass from the level below, then it cannot have more mass than that level (you cannot weigh more than you eat). The "missing" mass, which is not eaten by consumers, becomes detritus and is decomposed.



3. Pyramids of Energy

Food chains represent flows of matter and energy, so two different pyramids are needed to quantify each flow. Pyramids of energy show how much energy flows into each trophic level in a given time, so the units are usually something like kJ m^{-2} y^{-1}. Pyramids of energy are always pyramidal (energy cannot be created), and always very shallow, since the transfer of energy from one trophic level to the next is very inefficient The "missing" energy, which is not passed on to the next level, is lost eventually as heat.

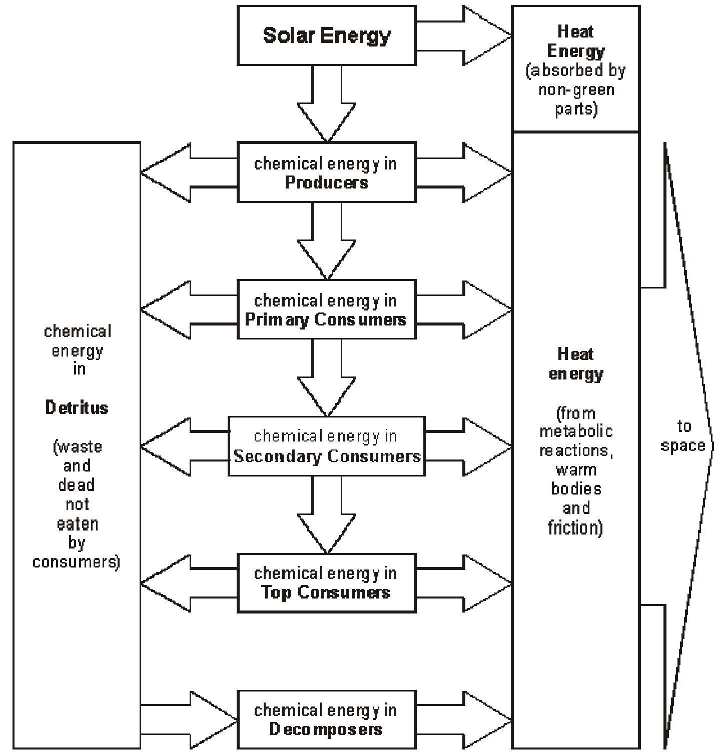


Energy Flow in Ecosystems

Three things can happen to the energy taken in by the organisms in a trophic level:

- It can be passed on to the biomass of the next trophic level in the food chain when the organism is eaten.
- It can become stored in detritus. This energy is passed on to decomposers when the detritus decays.
- It can be converted to heat energy by inefficient chemical reactions, radiated by warm bodies, or in friction due to movement. The heat energy is lost to the surroundings, and cannot be regained by living organisms.

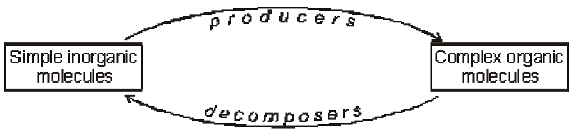
These three fates are shown in this energy flow diagram:



Eventually all the energy that enters the ecosystem will be converted to heat, which is lost to space.

Material Cycles in Ecosystems

Matter cycles between the biotic environment and in the abiotic environment. Simple inorganic molecules (such as CO_2, N_2 and H_2O) are assimilated (or fixed) from the abiotic environment by producers and microbes, and built into complex organic molecules (such as carbohydrates, proteins and lipids). These organic molecules are passed through food chains and eventually returned to the abiotic environment again as simple inorganic molecules by decomposers. Without either producers or decomposers there would be no nutrient cycling and no life.



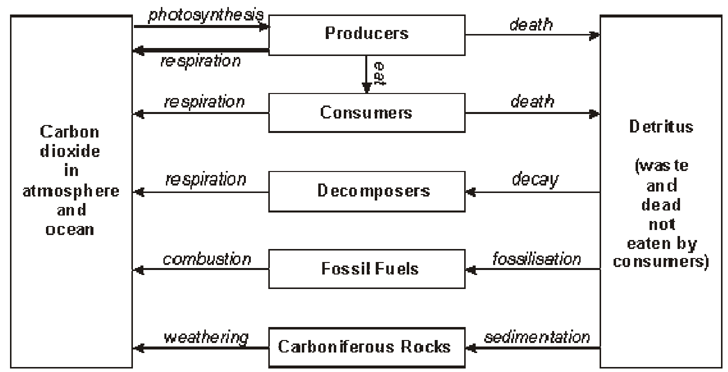
The simple inorganic molecules are often referred to as nutrients. Nutrients can be grouped as: major nutrients (molecules containing the elements C, H and O, comprising >99% of biomass); macronutrients (molecules containing elements such as N, S, P, K, Ca and Mg, comprising 0.5% of biomass); and micronutrients or trace elements (0.1% of biomass). Macronutrients and micronutrients are collectively called minerals. While the major nutrients are obviously needed in the largest amounts, the growth of producers is usually limited by the availability of minerals such as nitrate and phosphate.

There are two groups of decomposers:

- Detrivores are animals that eat detritus (such as earthworms and woodlice). They digest much of the material, but like all animals are unable to digest the cellulose and lignin in plant cell walls. They break such plant tissue into much smaller pieces with a larger surface area making it more accessible to the saprophytes. They also assist saprophytes by excreting useful minerals such as urea, and by aerating the soil.
- Saprophytes (or decomposers) are microbes (fungi and bacteria) that live on detritus. They digest it by extracellular digestion, and then absorb the soluble nutrients. Given time, they can completely break down any organic matter (including cellulose and lignin) to inorganic matter such as carbon dioxide, water and mineral ions.

Detailed material cycles can be constructed for elements such as carbon, nitrogen, oxygen or sulphur, or for compounds such as water, but they all have the same basic pattern as the diagram above. We shall only study the carbon and nitrogen cycles in detail.

The Carbon Cycle

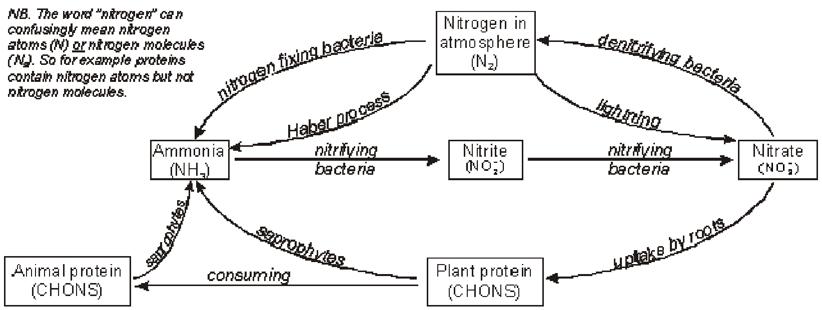


As this diagram shows, there are really many carbon cycles here with time scales ranging from minutes to millions of years. Microbes play the major role at all stages.

- Far more carbon is fixed by microscopic marine producers (algae and phytoplankton) from CO_2 dissolved in the oceans than by terrestrial plants from CO_2 in the air.
- During the Earth's early history (3000 MY ago) photosynthetic bacteria called cyanobacteria changed the composition of the Earth's atmosphere by fixing most of the CO_2 and replacing it with oxygen. This allowed the first heterotrophic cells to use oxygen in respiration.
- A large amount of the fixed carbon is used by marine zooplankton to make calcium carbonate shells. These are not eaten by consumers and cannot easily be decomposed, so turn into carboniferous rocks (chalk, limestone, coral, etc). 99% of the Earth's carbon is in this form.
- The decomposers are almost all microbes such as fungi and bacteria. Most of the detritus is in the form of cellulose and other plant fibres, which eukaryotes cannot digest. Only a few bacteria posses the cellulase enzymes required to break down plant fibres. Herbivorous animals such as cows and termites depend on these bacteria in their guts.
- Much of the CO_2 that was fixed by ferns during the carboniferous era (300 MY ago) was sedimented and turned into fossil fuels. The recent mining and burning of fossil fuels has

significantly altered the carbon cycle by releasing the carbon again, causing a 15% increase in CO_2 in just 200 years.

The Nitrogen Cycle



Microbes are involved at most stages of the nitrogen cycle:

Nitrogen Fixation. 78% of the atmosphere is nitrogen gas (N_2), but this is inert and can't be used by plants or animals. Nitrogen fixing bacteria reduce nitrogen gas to ammonia ($N_2 + 6H$ g $2NH_3$), which dissolves to form ammonium ions (NH_4^+). This process uses the enzyme nitrogenase and ATP as a source of energy. The nitrogen-fixing bacteria may be free-living in soil or water, or they may live in colonies inside the cells of root nodules of leguminous plants such as clover or peas. This is an example of mutualism as the plants gain a source of useful nitrogen from the bacteria, while the bacteria gain carbohydrates and protection from the plants. Nitrogen gas can also be fixed to ammonia by humans using the Haber process, and a small amount of nitrogen is fixed to nitrate by lightning.

Nitrification. Nitrifying bacteria can oxidise ammonia to nitrate in two stages: first forming nitrite ions NH_4^+gNO^-_2 then forming nitrate ions NO^-_2gNO^-_3. These are chemosynthetic bacteria, which means they use the energy released by nitrification to live, instead of using respiration. Plants can only take up nitrogen in the form of nitrate.

Denitrification. The anaerobic denitrifying bacteria convert nitrate to N_2 and NO_x, which is then lost to the air. This represents a constant loss of "useful" nitrogen from soil, and explains why nitrogen fixation by the nitrifying bacteria and fertilisers are so important.

Ammonification. Microbial saprophytes break down proteins in detritus to form ammonia in two stages: first they digest proteins to amino acids using extracellular protease enzymes, then they remove the amino groups from amino acids using deaminase enzymes.

Human Impact on the Environment

Ecological Impact of Farming

One of the main reasons for studying ecology is to understand the impact humans are having on the planet. The huge increases in human population over the last few hundred years has been possible due to the development of intensive farming, including monoculture, selective breeding, huge farms, mechanisation and the use of chemical fertilisers and pesticides. However, it is apparent that this intensive farming is damaging the environment and is becoming increasingly difficult to sustain. Some farmers are now turning to environmentally-friendly organic farming. We'll examine 5 of the main issues and their possible solutions.

1. Monoculture

Until the middle of the 20th century, farms were usually small and mixed (i.e. they grew a variety of crops and kept animals). About a third of the population worked on farms. The British countryside was described by one observer in 1943 as "*an attractive patchwork with an infinite variety of small odd-shaped fields bounded by twisting hedges, narrow winding lanes and small woodlands*". Today the picture is quite different, with large uninterrupted areas of one colour due to specialisation in one crop - monoculture. Monoculture increases the productivity of farmland by growing only the best variety of crop; allowing more than one crop per year; simplifying sowing and harvesting of the crop; and reducing labour costs.

However, monoculture has a major impact on the environment:

- Using a single variety of crop reduces genetic diversity and renders all crops in a region susceptible to disease.
- Fertilisers are required to maintain soil fertility. This is expensive and can pollute surrounding groundwater due to leaching.
- Pesticides are required to keep crops healthy. Again this is expensive and potentially polluting.
- Monoculture reduces species diversity. This has many knock-on effects such as allowing a pest species to get out of control, fewer plants due to lack of pollinating insects and loss of species that may be useful to humans.
- Less attractive countryside.

Some farmers are now returning to traditional crop rotations, where different crops are grown in a field each year. This breaks the life cycles of pests (since their host is changing); improves soil texture (since different crops have different root structures and methods of cultivation); and can increase soil nitrogen (by planting nitrogen-fixing legumes).

2. Hedgerows

Hedges have been planted since Anglo-Saxon times to mark field boundaries and to contain livestock. As they have matured they have diversified to contain a large number of different plant and animal species, some found nowhere else in the UK. Since the Second World War much of the hedgerow has been removed because:

- As mixed farms converted to arable farms, hedgerows are no longer needed to contain livestock.
- Many small farms have been amalgamated into large farms, allowing larger fields, which in turn allows greater mechanisation and lower labour costs. One farmer found that by removing 1.5 miles of hedges, he increased his arable land by 3 acres and reduced harvesting time by one third.
- Hedgerows reduce the space available for planting crops, and their roots compete with those of crops for water and minerals in the soil.
- Hedgerows provide shelter for pests such as rabbits and insects, and they are a reservoir of weeds and disease.
- Hedgerows need to be maintained, which is a skilled job, costing time and money.

However it has now become clear that hedgerows served an important place in the ecology of Britain.

- They provide habitats for at least 30 species of trees and shrubs, 65 species of nesting birds, 1500 species of insects and 600 species of wildflowers. These in turn provide food for small mammals.
- They act as corridors, allowing animals to move safely between woodlands.
- Some of the animals they shelter are predators of plant pests, so they may reduce pests, not increase them.
- They are efficient windbreaks, providing shelter for animals and plants, and reducing soil erosion. During storms in recent years large amounts of topsoil was blown away from large unsheltered fields.
- They provide habitats for pollinating insects, so removing hedgerows can indirectly reduce the populations of other local plant species.
- In the UK we have surpluses of many crops, and farmers can receive grants to reduce their food production.

The importance of hedgerows is now being recognised, and farmers can now receive grants to plant hedgerows. However it takes hundreds of years for new hedgerows to mature and develop the same diversity as the old ones.

3. Fertilisers

Since the rate of plant growth in usually limited by the availability of mineral ions in the soil, then adding more of these ions as fertiliser is a simple way to improve yields, and this is a keystone of intensive farming. The most commonly used fertilisers are the soluble <u>inorganic fertilisers</u> containing nitrate, phosphate and potassium ions (NPK). Inorganic fertilisers are very effective but also have undesirable effects on the environment. Since nitrate and ammonium ions are very soluble, they do not remain in the soil for long and are quickly leached out, ending up in local rivers and lakes and causing eutrophication. They are also expensive.

An alternative solution, which does less harm to the environment, is the use of <u>organic fertilisers</u>, such as animal manure (farmyard manure or FYM), composted vegetable matter, crop residues, and sewage sludge. These contain the main elements found in inorganic fertilisers (NPK), but in organic compounds such as urea, cellulose, lipids and organic acids. Of course plants cannot make use of these organic materials in the soil: their roots can only take up inorganic mineral ions such as nitrate, phosphate and potassium. But the organic compounds can be digested by soil organisms such as animals, fungi and bacteria, who then release inorganic ions that the plants can use (refer to the nitrogen cycle). Some advantages of organic fertilisers are:

- Since the compounds in organic fertilisers are less soluble than those in inorganic fertilisers, the inorganic minerals are released more slowly as they are decomposed. This prevents leaching and means they last longer.
- The organic wastes need to be disposed of anyway, so they are cheap. Furthermore, spreading on to fields means they will not be dumped in landfill sites, where they may have caused uncontrolled leaching.
- The organic material improves soil structure by binding soil particles together and provides food for soil organisms such as earthworms. This improves drainage and aeration.

Some disadvantages are that they are bulky and less concentrated in minerals than inorganic fertilisers, so more needs to be spread on a filed to have a similar effect. They may contain unwanted substances such as weed seeds, fungal spores, heavy metals. They are also very smelly!

4. Pesticides

To farmers, a pest is any organism (animal, plant or microbe) that damages their crops. Some form of pest control has always been needed, whether it is chemical (e.g. pesticides), biological (e.g. predators) or cultural (e.g. weeding or a scarecrow). Chemicals pesticide include:

- herbicides anti-plant chemicals
- insecticides anti-insect chemicals
- fungicides anti-fungal chemicals
- bactericides anti-bacterial chemicals

Pesticides have to be effective against the pest, but have no effect on the crop. They may kill the pests, or just reduce their population by slowing growth or preventing reproduction. Intensive farming depends completely on the use of pesticides, and some wheat crops are treated with 18 different chemicals to combat a variety of weeds, fungi and insects. In addition, by controlling pests that carry human disease, they have saved millions of human lives. However, with their widespread use and success there are problems, the mains ones being persistence and bioaccumulation.

Both of these are illustrated by DDT (DichloroDiphenylTrichloroethane), an insecticide used against the malaria mosquito in the 1950s and 60s very successfully, eradicating malaria from southern Europe. However the population of certain birds fell dramatically while it was being used, and high concentrations of DDT were found in their bodies, affecting calcium metabolism and causing their egg shells to be too thin and fragile. DDT was banned in developed countries in 1970, and the bird populations have fully recovered. Alternative pesticides are now used instead, but they are not as effective, and continued use of DDT may have eradicated malaria in many more places.

Persistence. This refers to how long a pesticide remains active in the environment. Some chemicals are broken down by decomposers in the soil (they're biodegradable) and so are not persistent, while others cannot be broken down by microbes (they're non biodegradable) and so continue to act for many years, and are classed as persistent pesticides. The early pesticides (such DTT) were persistent and did a great deal of damage to the environment, and these have now largely been replaced with biodegradable insecticides such as carbamates and pyrethroids.

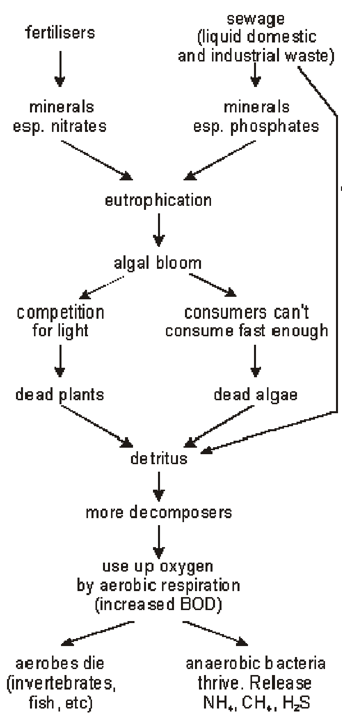
Bioaccumulation (or Biomagnification). This refers to the built-up of a chemical through a food chain. DDT is not soluble in water and is not excreted easily, so it remains in the fat tissue of animals. As each consumer eats a large mass of the trophic level below it, DTT accumulates in the fat tissue of animals at the top of the food chain. This food chain shows typical concentrations of DDT found in a food chain (in parts per million, ppm):

water → zooplankton 0.04 ppm → small fish 0.5 ppm → large fish 2 ppm → birds 25 ppm

The high concentration of DDT in birds explains why the toxic effects of DDT were first noticed in birds.

5. Eutrophication

Eutrophication refers to the effects of nutrients on aquatic ecosystems. These naturally progress from being oligotrophic (clean water with few nutrients and algae) to eutrophic (murky water with many nutrients and plants) and sometimes to hypertrophic (a swamp with a mass of plants and detritus). This is in fact a common example of succession. In the context of pollution "eutrophication" has come to mean a sudden and dramatic increase in nutrients due to human activity, which disturbs and eventually destroys the food chain. The main causes are fertilisers leaching off farm fields into the surrounding water course, and sewage (liquid waste from houses and factories). These both contain dissolved minerals, such as nitrates and phosphates, which enrich the water.



Since producer growth is generally limited by availability of minerals, a sudden increase in these causes a sudden increase in producer growth. Algae grow faster than larger plants, so they show a more obvious "bloom", giving rise to spectacular phenomena such as red tides. Algae produce oxygen, so at this point the ecosystem is well oxygenated and fish will thrive.

However, the fast-growing algae will out-compete larger plants for light, causing the plants to die. The algae also grow faster than their consumers, so many will die without being consumed, which is not normal. These both lead to a sudden increase in detritus. Sewage may also contain organic matter, which adds to the detritus.

Decomposing microbes can multiply quickly in response to this, and being aerobic they use up oxygen faster than it can be replaced by photosynthesis or diffusion from the air. The decreased oxygen concentration kills larger aerobic animals and encourages the growth of anaerobic bacteria, who release toxic waste products.

Biochemical Oxygen Demand (BOD). This measures the rate of oxygen consumption by a sample of water, and therefore gives a good indication of eutrophication. A high BOD means lots of organic material and aerobic microbes, i.e. eutrophication. The method is simple: a sample of water is taken and its O_2 concentration is measured using an oxygen meter. The sample is then left in the dark for 5 days at 20°C, and the O_2 is measured again. The BOD is then calculated from: original O_2 concentration – final O_2 concentration. The more oxygen used up over the 5 days (in mg.dm^{-3}) the higher the BOD, and the higher the BOD the more polluted the water is. This table shows some typical BOD values.

	BOD (mg.dm^{-3})
clean water	3
polluted water	10
cleaned sewage	20 (legal max)
raw sewage	300

Aquatic ecosystems can slowly recover from a high BOD as oxygen dissolves from the air, but long-term solutions depend on reducing the amount of minerals leaching into the water. This can be achieved by applying inorganic fertilisers more carefully, by using organic fertilisers, by using low-phosphate detergents, and by removing soluble minerals by precipitation in modern sewage plants. As a last resort eutrophic lakes can be dredged to remove mineral-rich sediment, but this is expensive and it takes a long time for the ecosystem to recover. This has been done in the Norfolk Broads.

Deforestation

Human activities often affect whole ecosystems. There are potential conflicts between the need/wish to produce things useful to humans in the short term and the conservation of ecosystems in the long term.

Forests are the natural climax communities. They have high diversity, with complex food webs. Humans have been clearing areas of forest for thousands of years – leading to deforestation over large areas of Europe, Asia and North America. Recent and present deforestation affects manly tropical rain forests. Tropical rain forests have been estimated to contain 50% of the world's standing timber. They represent a huge store of carbon and sink for carbon dioxide and their destruction may increase atmospheric concentrations of carbon dioxide by 50%. They are important in conserving soil nutrients and preventing large-scale erosion in regions of high rainfall. They contain a large gene pool of plant resources.

Deforestation leads to the increase in land for agriculture

- Growth in the human population is increasing demand for land for farming.
- Deforestation causes local extinction of species of trees. This particularly affects hardwoods, which are in demand for timber, and softwoods for making paper.

Deforestation affects diversity

Loss of trees:

- Removes the bases of many food webs
- Removes the habitats of many other species
- Causes local extinction of other populations, or reduction in their size
- Reduced the number of species present and numbers of individuals present
- Reduces diversity
- Leads to a lower biomass and productivity per hectare.

Reducing the diversity produces a less stable and more extreme environment, where abiotic factors also become more extreme.

Deforestation affects carbon and nitrogen cycles

- Means less photosynthesis
- Usually involves burning unwanted trees, and expanding human populations burn more wood for fuel.
- With the trees gone (mainly in tropical rain forests) there has been large scale erosion due to the high rainfall in these area washing away the soil.
- Less carbon dioxide is removed from the atmosphere and more is added. This adds to the problem of global warming
- In forests, most of the nitrate ions (and other mineral ions) absorbed by plants come from decomposition of organic remains – the ions are recycled
- Many of the decomposing fungi live in association with the roots of trees
- The soil is often a poor source of mineral ions.

Deforestation results in:

- Reduced input to the nitrogen cycle
- Slower and less recycling of nitrates (and other ions)
- Increased loss of nitrates by leeching

The soil loses fertility can support lower numbers and fewer species of plants → lower diversity

Conservation of forests

Conservation involves managing the Earth's resources so as to restore and maintain a balance between the requirements of humans and those of other species. Many attempts are being made to encourage sustainable use of forests. This involves measuring and comparing yields and profits from deforestation with alternative uses.

A study in 1989 (obviously the figures will be much different now) of an Amazon rainforest in Peru showed that each hectare of the forest produces fruit and latex (rubber) with an annual market value of $700. If, however, the trees are cut down, the total value of their wood is $1000. Now, trees can only be felled once, but fruit and latex can be harvest every year. This study into sustainable management can allow governments to be persuaded that more money can be made from rainforests by exploiting them on a sustainable basis than by destroying them, therefore it may be worth their while to preserve them.

5.2.3 Explain the relationship between rises in concentrations of atmospheric carbon dioxide, methane and oxides of nitrogen and the enhanced greenhouse effect.

The earths mean average temperature is regulated by a steady equilibrium which exists between the energy reaching the earth from the sun and the energy reflected by the earth back into space. The incoming radiation is short wave ultraviolet and visible radiation. Some of the radiation will be absorbed by the atmosphere and some of it will be reflected back from the earths surface into space. The radiation that is reflected back into space is infrared radiation which has a longer wavelength. Green house gases such as carbon dioxide, methane, and oxides of nitrogen tend to absorb some of the reflected infrared radiation and re-reflect it back towards the earth. This is what causes the greenhouse effect and it results in an increase in average mean temperature on earth. It is a natural phenomenon. However, since there has been an increase in the green house gases in the past century, this has resulted in an increase of the green house effect leading to higher than normal average temperatures which could lead to disastrous consequences in the future.

Summary:

1. The incoming radiation from the sun is short wave ultraviolet and visible radiation.
2. Some of this radiation is absorbed by the earths atmosphere.
3. Some of the radiation is reflected back into space by the earths surface.
4. The radiation which is reflected back into space is infrared radiation and has a longer wavelength.
5. The greenhouse gases in the atmosphere absorbe some of this infrared radiation and re-reflect it back towards the earth.
6. This causes the green house effect and results in an increase in average mean temperatures on earth.
7. A rise in greenhouse gases results in an increase of the green house effect which can be disastrous for the planet.

5.2.4 Outline the precautionary principle.

The precautionary principle holds that, if the effects of a human-induced change would be very large, perhaps catastrophic, those responsible for the change must prove that it will not do harm before proceeding. This is the reverse of the normal situation, where those who are concerned about the change would have to prove that it will do harm in order to prevent such changes going ahead.

5.2.5 Evaluate the precautionary principle as a justification for strong action in response to the threats posed by the enhanced greenhouse effect.

There is strong evidence that shows that green house gases are causing global warming. This is very worrying as global warming has so many consequences on ecosystems. If nothing is done, and the green house gases are in fact causing the enhanced green house effect, by the time we realize it, it will probably be too late and result in catastrophic consequences. So even though there is no proof for global warming, the strong evidence suggesting that it is linked with an increase in green house gases is something we can not ignore. Global warming is a global problem. It affects everyone. For these reasons, the precautionary principle should be followed. Anyone supporting the notion that we can continue to emit same amounts or more of the green house gases should have to provide evidence that it will not cause a damaging increase in the green house effect.

5.2.6 Outline the consequences of a global temperature rise on arctic ecosystems.

Global warming could have a number of disastrous consequences largely affecting the arctic ecosystems:

- The arctic ice cap may disappear as glaciers start to melt and break up into icebergs.
- Permafrost will melt during the summer season which will increase the rate of decomposition of trapped organic matter, including peat and detritus. This in turn will increase the release of carbon dioxide which will increase the green house effect even further.
- Species adapted to temperature conditions will migrate north which will alter food chains and have consequences on the animals in the higher trophic levels.
- Marine species in the arctic water may become extinct as these are very sensitive to temperature changes within the sea water.
- Polar bears may face extinction as they loose their ice habitat and therefore can no longer feed or breed as they normally would.
- Pests and diseases may become quite common with rises in temperature.
- As the ice melts, sea levels will rise and flood low lying areas of land.
- Extreme weather events such as storms might become common and have disastrous effects on certain species.

Speciation

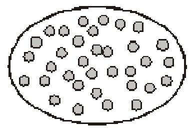
A species is defined as a group of interbreeding populations that are reproductively isolated from other groups. Reproductively isolated can mean that sexual reproduction between different species is impossible for physical, ecological, behavioural, temporal or developmental reasons. For example horses and donkeys can apparently interbreed, but the offspring (mule) doesn't develop properly and is infertile. This definition does not apply to asexually reproducing species, and in some cases it is difficult distinguish between a strain and a species.

New species usually develop due to:

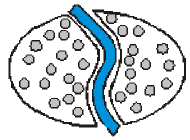
- geographical isolation (allopatric speciation)
- reproductive isolation (sympatric speciation)

Geographical Isolation (Allopatric Speciation)

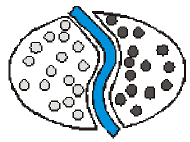
1. Start with an interbreeding population of one species.



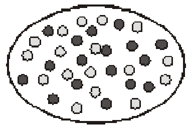
2. The population becomes divided by a physical barrier such as water, mountains, desert, or just a large distance. This can happen when some of the population migrates or is dispersed, or when the geography changes catastrophically (e.g. earthquakes, volcanoes, floods) or gradually (erosion, continental drift).



3. If the two environments (abiotic or biotic) are different (and they almost certainly will be), then the two populations will experience different selection pressures and will evolve separately. Even if the environments are similar, the populations may change by random genetic drift, especially if the population is small.



4. Even if the barrier is removed and the two populations meet again, they are now so different that they can no longer interbreed. They are therefore reproductively isolated and are two distinct species. They may both be different from the original species, if it still exists elsewhere.



It is meaningless to say that one species is absolutely better than another species, only that it is better adapted to that particular environment. A species may be well-adapted to its environment, but if the environment changes, then the species must adapt or die. In either case the original species will become extinct. Since all environments change eventually, it is the fate of all species to become extinct (including our own).

Reproductive Isolation (Sympatric Speciation)

Reproductive Isolation is a type of genetic isolation. Here the formation of a new species can take place in the <u>same</u> geographical area, e.g. mutations may result in reproductive incompatibility. A new gene producing, say, a hormone, may lead an animal to be rejected from the mainstream group, but breeding may be possible within its own groups of variants. When this mechanism results in the production of a new species it is known as <u>sympatric speciation.</u>