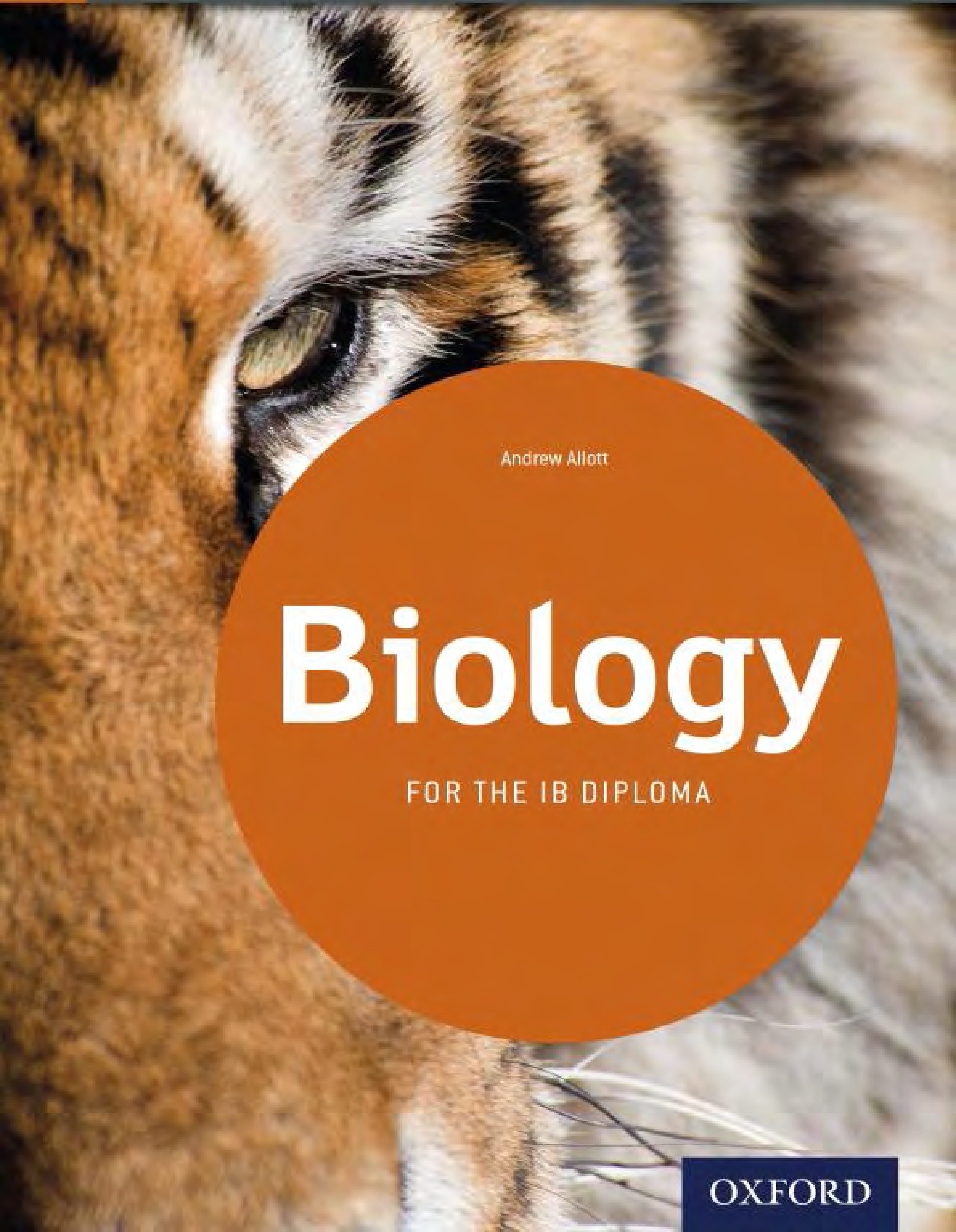
OXFORD IB STUDY GUIDE



Andrew Allott

Biology

FOR THE IB DIPLOMA

OXFORD

Identifying living organisms

USING KEYS TO IDENTIFY ORGANISMS

The first stage in many ecological investigations is to find out what species of organism there are in the area being studied. This is called **species identification**. This can be done using **keys**.

Keys for species identification are usually constructed in this way:

- the key consists of a series of numbered stages
- each stage consists of a pair of alternative characteristics
- some alternatives give the next stage of the key to go to
- some alternatives give the identification.

Identifying aquarium plants using a key

Many aquatic plants in aquariums in biology laboratories belong to one of these four genera:

- *Cabomba*
- *Ceratophyllum*
- *Elodea*
- *Myriophyllum*

All of these plants have cylindrical stems with whorls of leaves. The shape of four leaves is shown in the figure (left). A key can be used to identify which of the four genera a plant belongs to, if it is known to be in one of them.

1. Simple undivided leaves . . . . *Elodea*

   Leaves forked or divided into segments 2

2. Leaves forked once or twice to form two or four segments . . . . *Ceratophyllum*

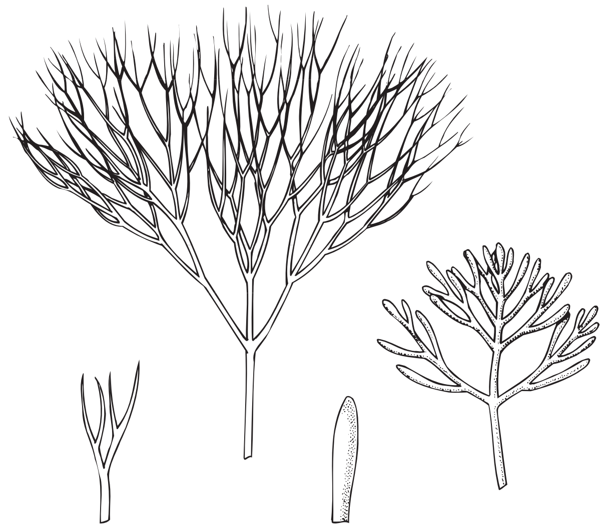
   Leaves divided into more than four segments 3

3. Leaves divided into many flattened segments . . . . *Cabomba*

   Leaves divided into many filamentous segments . . . . *Myriophyllum*

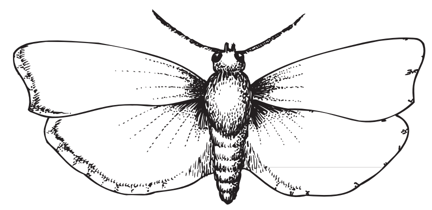
Some species of Elodea have recently been moved by taxonomists to other genera:
Elodea densa is now *Egeria densa*.
Elodea crispa is now *Lagarosiphon major*.

Leaves of aquarium plants

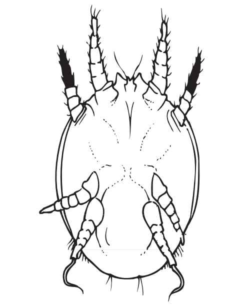


Constructing a key

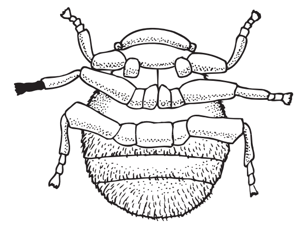
The five animals shown below are found in beehives. It would be useful to construct a key to allow a beekeeper to identify them, as some of them are very harmful and others are harmless to honey bees.



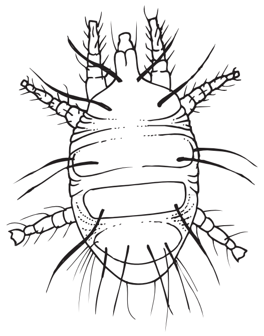
Galleria mellonella



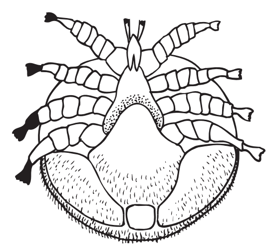
Acarus siro



Braula coeca



Acarapis woodi



Varroa jacobsonii

BINOMIAL NOMENCLATURE

In the classification of living organisms, the basic group is the **species**.

A species is a group of organisms with similar characteristics, which can interbreed and produce fertile offspring.

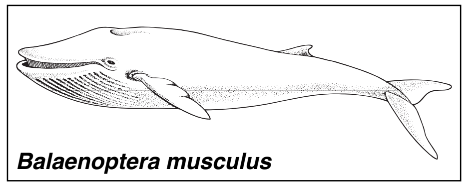
Every species is classified into a **genus**. A genus is a group of similar species.

Each species needs an international name, so that biologists throughout the world can refer to it. The naming of species is called **nomenclature**. The nomenclature that biologists use is called the **binomial system** because two names are used to refer to each species. The key features of the binomial system of nomenclature are:

- the first name is the genus name
- the genus name is given an upper case first letter
- the second name is the species name
- the species name is given a lower case first letter
- italics are used when the name is printed
- the name is underlined if it is hand-written.

Classification of plants and animals

CLASSIFICATION FROM SPECIES TO KINGDOM



Balaenoptera musculus

A group of organisms, such as a species or a genus is called a **taxon**. Species are classified into a series of taxa, each of which includes a wider range of species than the previous one. This is called the **hierarchy of taxa**.

	Animal example Balaenoptera musculus – the blue whale (left)	**Plant example Sequoia sempervirens – the coast redwood (right)**
Species that are similar are grouped into a genus	Genus Balaenoptera	Genus Sequoia
Genera that are similar are grouped into a family	Family Balaenopteridae	Family Taxodiaceae
Families that are similar are grouped into an order	Order Cetacea	Order Pinales
Orders that are similar are grouped into a class	Class Mammalia	Class Pinopsida
Classes that are similar are grouped into a phylum	Phylum Chordata	Phylum Coniferophyta
Phyla that are similar are grouped into a kingdom	Kingdom Animalia	Kingdom Plantae

Sequoia sempervirens

Plant classification

There are four main phyla of plants, which can be easily distinguished by studying their external structure.

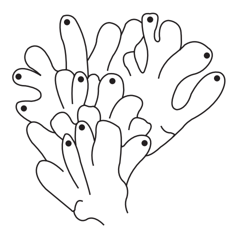
	Roots, leaves and stems	**Maximum height**	**Reproductive structures**
Bryophytes – mosses	Bryophytes have no roots, only structures similar to root hairs called **rhizoids** Mosses have simple leaves and stems Liverworts consist of a flattened thallus	0.5 metres	Spores are produced in a capsule. The capsule develops at the end of a stalk
Filicinophytes – ferns	Ferns have roots, leaves and short non-woody stems. The leaves are usually curled up in bud and are often **pinnate** – divided into pairs of leaflets	15 metres	Spores are produced in sporangia, usually on the underside of the leaves
Coniferophytes – conifers	Conifers are shrubs or trees with roots, leaves and woody stems. The leaves are often narrow with a thick waxy cuticle	100 metres	Seeds are produced. The seeds develop from ovules on the surface of the scales of female **cones**. Male cones produce pollen
Angiospermophytes – flowering plants	Flowering plants are very variable but usually have roots, leaves and stems. The stems of flowering plants that develop into shrubs and trees are woody	100 metres	Seeds are produced. The seeds develop from ovules inside **ovaries**. The ovaries are part of **flowers**. **Fruits** develop from the ovaries, to disperse the seed

ANIMAL CLASSIFICATION

There are over thirty phyla of animals. The external recognition features of six of these phyla are shown here.

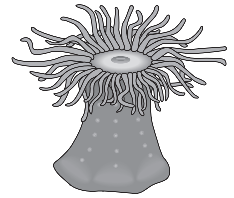
Porifera
- no clear symmetry
- attached to a surface
- pores through body
- no mouth or anus

Examples: *sponges*



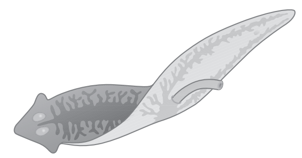
Cnidaria
- radially symmetric
- tentacles
- stinging cells
- mouth but no anus

Examples: *jellyfish, corals, sea anemones*



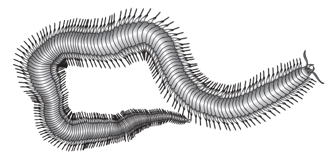
Platyhelminths
- bilaterally symmetric
- flat bodies
- unsegmented
- mouth but no anus

Examples: *Planaria, tapeworms, liverflukes*



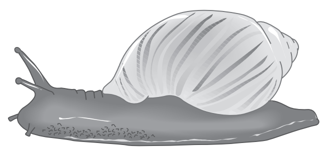
Annelida
- bilaterally symmetric
- bristles often present
- segmented
- mouth and anus

Examples: *earthworms, leeches, ragworms*



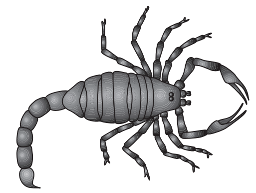
Mollusca
- muscular foot and mantle
- shell usually present
- segmentation not visible
- mouth and anus

Examples: *slugs, snails, clams, squids*



Arthropoda
- bilaterally symmetric
- exoskeleton
- segmented
- jointed appendages

Examples: *insects, spiders, crabs, millipedes*



Population dynamics

CHANGES TO THE SIZE OF A POPULATION

A population is a group of organisms of the same species, who live in the same area at the same time.

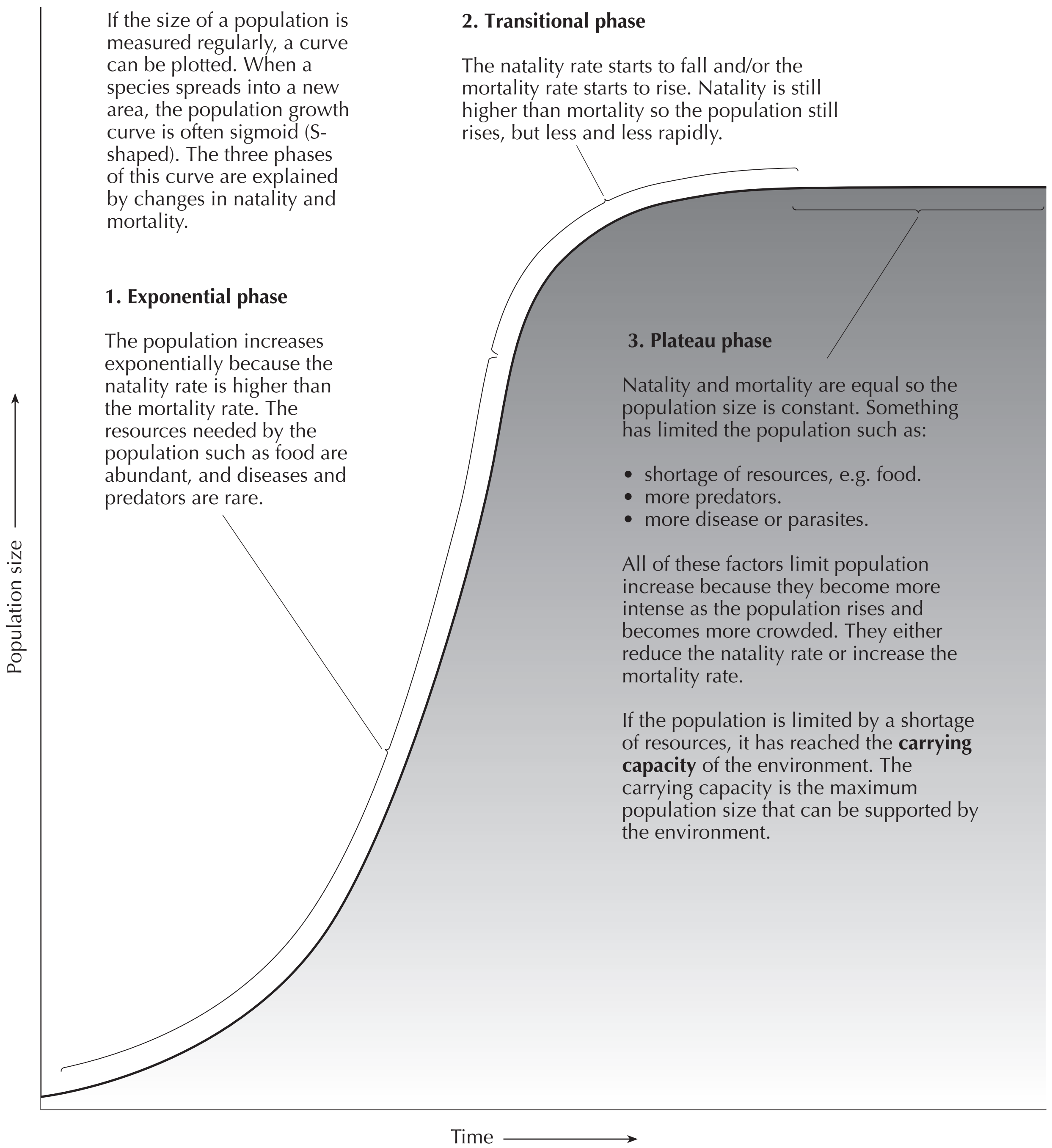
There are four ways in which the size of a population can change:

- Offspring are produced and are added to the population – **natality**.
- Individuals die and are lost from the population – **mortality**.
- Individuals move into the area from elsewhere and are added to the population – **immigration**.
- Individuals move out of the area to live elsewhere – **emigration**.

Populations are often affected by all four of these things and the overall change can be calculated using an equation:

Population change = (natality + immigration) – (mortality + emigration)

POPULATION GROWTH CURVES



Evidence for evolution

EVOLUTION OF POPULATIONS

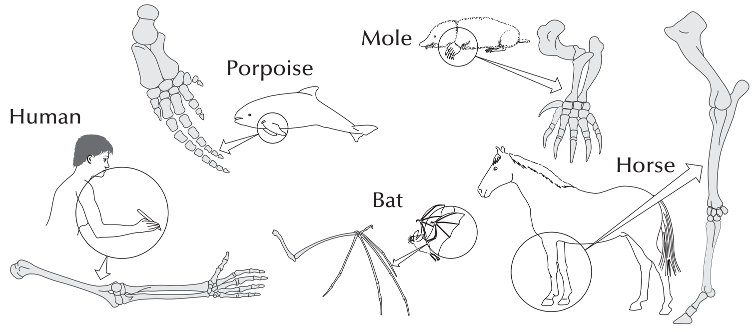
The word evolution has several meanings, all of which involve the gradual development of things. In biology, the word has come to mean the changes that occur in living organisms, over many generations. Evolution happens in populations of living organisms. It only happens with characteristics that can be inherited.

Evolution is the cumulative change in the heritable characteristics of a population.

Although it is not possible to prove, using the scientific method, that the organisms on Earth today are the result of evolution, there is much evidence that makes it very likely. Three types of evidence are illustrated on this page.

HOMOLOGOUS ANATOMICAL STRUCTURES

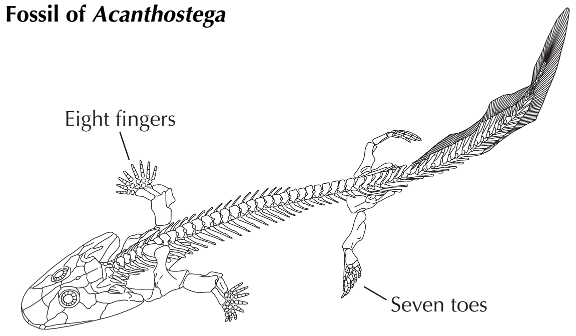
There are also remarkable similarities between some groups of organisms in their structure. For example, bones in the limbs of vertebrates are strikingly similar, despite being used in many different ways (below). The structure is called the pentadactyl limb.



The most likely explanation for these structural similarities is that the organisms have evolved from a common ancestor. Structures that have developed from the same part of a common ancestor are called homologous structures.

THE FOSSIL RECORD – PALAEONTOLOGY

Fossil of *Acanthostega*



The existence of fossils is very difficult to explain without evolution. An example of this is *Acanthostega*. The figure (left) is a drawing of a 365 million year old fossil of *Acanthostega*. It has similarities to other vertebrates, with a backbone and four limbs, but it has eight fingers and seven toes, so it is not identical to any existing organism. This suggests that vertebrates and other organisms change over time. *Acanthostega* is an example of a "missing link". Although it has four legs, like most amphibians, reptiles and mammals, it also had a fish-like tail and gills and lived in water. This shows that land vertebrates could have evolved from fish via an aquatic animal with legs.

SELECTIVE BREEDING OF DOMESTICATED ANIMALS

The breeds of animal that are reared for human use are clearly related to wild species and in many cases can still interbreed with them. These domesticated breeds have been developed from wild species, by selecting individuals with desirable traits, and breeding from them. The striking differences in the heritable characteristics of domesticated breeds give us evidence that species can evolve rapidly.

Spanish, Hamburgh and Polish Fowl, illustrated in *Breeds of Animals and Plants under Domestication* by Charles Darwin

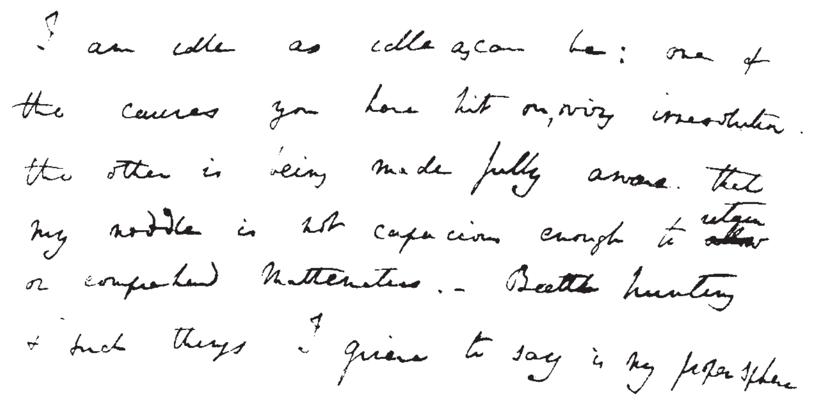
Natural selection

DARWIN, WALLACE AND EVOLUTION BY NATURAL SELECTION

Charles Darwin developed the theory that evolution occurs as a result of natural selection. He explained his theory in *The Origin of Species*, published in 1859. He had done many years of research and had collected much evidence for the theory before then.
Darwin delayed publication of his ideas for many years, fearing a hostile reaction. He might never have published them if another biologist, Alfred Wallace, had not written a letter to him in 1858 suggesting very similar ideas.
The theory of evolution by natural selection can be explained in a series of observations and deductions.
The photograph on the right shows a statue of Charles Darwin at Shrewsbury School, where he was a pupil from 1818 to 1825.

Observations		Deductions
* Populations of living organisms tend to increase exponentially * Yet, on the whole, the number of individuals in populations remains nearly constant	→	* More offspring are produced than the environment can support * There is a struggle for existence in which some individuals survive and some die
* Living organisms vary. The members of a species are different from each other in many ways * Some individuals have characteristics that make them well adapted to their environment and other individuals have characteristics that make them less well adapted to their environment	→	* The better adapted individuals tend to survive and reproduce more than the less well-adapted individuals This is **natural selection**
* Much variation is heritable – it can be passed on to offspring	→	* The better-adapted individuals pass on their characteristics to more offspring than the less well adapted individuals. The results of natural selection therefore accumulate * As one generation follows another, the characteristics of the species gradually change – the species evolves

In 1828 Darwin, as a young man was struggling to learn enough mathematics to pass a university exam.
The extract below is from a letter that he wrote to Charles Whitley, a friend and eminent mathematician.
' I am as idle as idle can be: one of the causes you have hit on, viz irresolution the other being made fully aware that my noddle is not capacious enough to retain or comprehend Mathematics. – Beetle hunting & such things I grieve to say is my proper sphere…'



Evolution in action

ENVIRONMENTAL CHANGE AND EVOLUTION

Since Darwin developed his theory of evolution by natural selection, changes have been observed in some species. In each case, the evolution has been in response to environmental change.
Two examples are described here – the development of antibiotic resistance in bacteria and melanism in ladybugs. Other examples include the development of metal tolerance in plants growing on waste material from mining metal ores, and changes to the beaks of finches on the Galápagos Islands in response to El Niño events.
All these recent cases of observed evolution involve relatively small changes, but they do nonetheless add to the evidence for evolution.

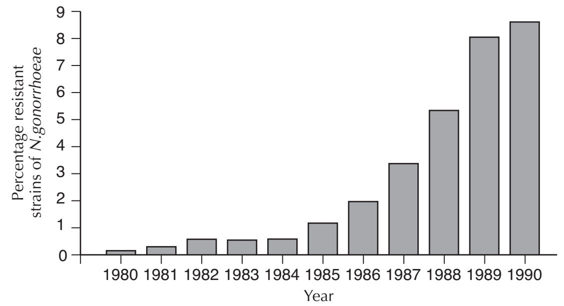
SEXUAL REPRODUCTION AND EVOLUTION

Variation is essential for natural selection and therefore for evolution. Although mutation is the original source of new genes or alleles, sexual reproduction promotes variation by allowing the formation of new combinations of alleles. Two stages in sexual reproduction promote variation.
1. Meiosis allows a huge variety of genetically different gametes to be produced by each individual.
2. Fertilization allows alleles from two different individuals to be brought together in one new individual.

Prokaryotes do not reproduce sexually but have other ways to promote variation by exchanging genes.
Some species of organisms only reproduce asexually. Mutations still produce some variation in these species, but without sexual reproduction the variation and the capacity for evolution is less.

Multiple antibiotic resistance in bacteria

Antibiotics are used to control diseases caused by bacteria in humans. There have been increasing problems with disease-causing bacteria being resistant to antibiotics. The figure below shows the percentage of cases of gonorrhea (a sexually transmitted disease) in the United States that were caused by antibiotic-resistant strains of *Neisseria gonorrhoeae* between 1980 and 1990. The trend with many other diseases has been similar.

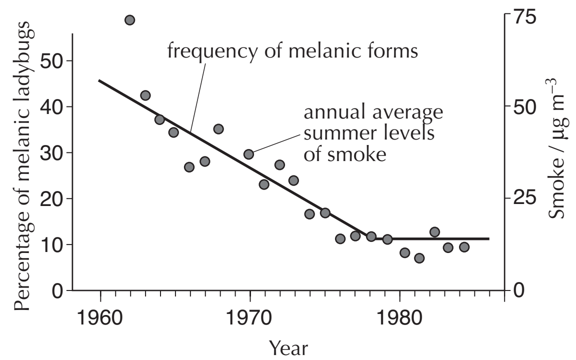


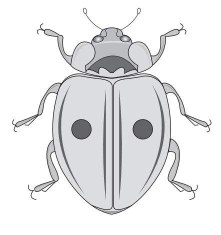
Genes that give resistance to an antibiotic can be found in the micro-organisms that naturally make that antibiotic.
The evolution of multiple antibiotic resistance involves the following steps.
- A gene that gives resistance to an antibiotic is transferred to a bacterium by means of a plasmid or in some other way. There is then variation in this type of bacterium – some of the bacteria are resistant to the antibiotic and some are not.
- Doctors or vets use the antibiotic to control bacteria. Natural selection favours the bacteria that are resistant to it and kills the non-resistant ones.
- The antibiotic-resistant bacteria reproduce and spread, replacing the non-resistant ones. Eventually, most of the bacteria are resistant.
- Doctors or vets change to a different antibiotic to control bacteria. Resistance to this soon develops, so another antibiotic is used, and so on until multiply resistant bacteria have evolved.

The more an antibiotic is used, the more bacteria resistant to it there will be and the fewer non-resistant.

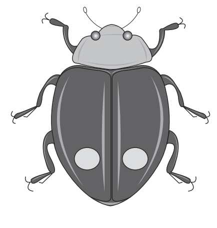
Evolution of melanism in ladybugs

Adalia bipunctata, the two-spot ladybug (or ladybird), is a small beetle, which usually has red wing cases with two black spots. The red colour warns predators that it tastes unpleasant. Melanic forms also exist, with black wing cases. The melanic form absorbs heat more efficiently than the red form. It therefore has a selective advantage when sunlight levels are low and it is difficult for ladybugs to warm up. The melanic form of *Adalia bipunctata* became common in industrial areas of Britain, but declined again after 1960. The decline correlates with decreases in smoke in the air (below). In air darkened by smoke, the melanic forms will be able to warm up more quickly, but if the smoke is no longer present this advantage is lost and warning colouration is more important.





Adalia 2-punctata
(f. *typica*)
2-spot ladybird (typical)

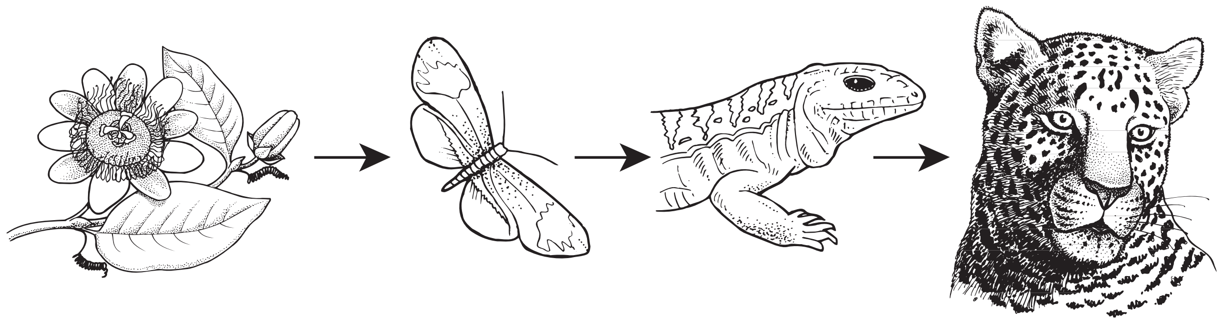


Adalia 2-punctata
(f. *quadrimaculata*)
2-spot ladybird (melanic)

Trophic levels

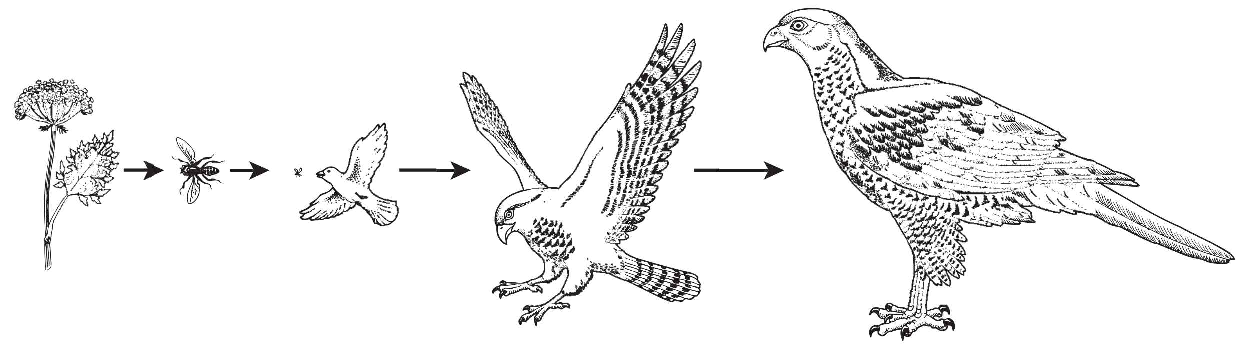
Populations do not live in isolation – they live together with other populations in **communities**. *A community is a group of populations living together and interacting with each other in an area.*
There are many types of interaction between populations in a community. Trophic relationships are very important – where one population of organisms feeds on another population. Sequences of trophic relationships, where each member in the sequence feeds on the previous one, are called **food chains**.

An example from rainforest at Iguazu in north-east Argentina.



Passionflower *(Passiflora schummaniana)* → Heliconius butterfly *(Heliconius erato)* → tegu lizard *(Tupinambis teguixin)* → jaguar *(Panthera onca)*

An example from chalk grassland and the air above it in Europe.



carrot plant *(Daucus carota)* → carrot fly *(Psila rosea)* → flycatcher *(Muscicapa striata)* → sparrowhawk *(Accipiter nisus)* → goshawk *(Accipiter gentilis)*

The first organism in a food chain does not feed on other organisms so must be a producer – an organism that makes its own food. The other organisms are all consumers and are called primary, secondary, tertiary and so on, depending on their position in the chain.
Producer, primary consumer, secondary consumer and tertiary consumer are examples of **trophic levels**. *The trophic level of an organism is its position in the food chain.*

Example:

Producer	→	**Primary consumer**	→	**Secondary consumer**	→	**Tertiary consumer**
Sea lettuce		Marine iguana		Galapagos snake		Galapagos hawk
(Ulva lactuca)		*(Amblyrhyncus cristatus)*		*(Dromiscus biserialis)*		*(Buteo galapagensis)*

A food chain shows only some of the trophic relationships in a community. Organisms rarely feed on only one other organism and are usually fed on by more than one organism. The complex network of trophic relationships in a community is shown in full in a complex diagram called a food web. An example of a food web is shown on page 42.

Energy flow

AUTOTROPHS

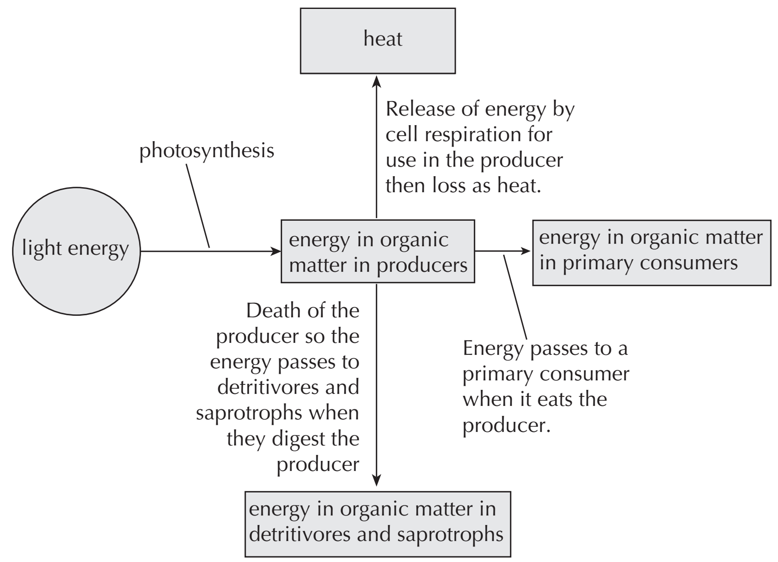
The organisms in a community all need a supply of energy. Organisms are divided into two groups according to their source – **autotrophs** and **heterotrophs**.

Autotrophs are organisms that synthesize their own organic molecules (food) from simple inorganic substances.

Autotrophs make their own food, so are also called producers. Oak trees, maize plants, algae, blue-green bacteria are examples.
All food chains start with a producer. In almost all communities, the producers make organic matter by photosynthesis.

Light is therefore the **initial energy source** for the whole community. Producers convert light energy into the chemical energy of sugars and other organic compounds. This energy trapped by the producers eventually leaves them in one of three ways, shown in the flow chart (right).

Energy flow through producers



HETEROTROPHS

Heterotrophs are organisms that obtain organic molecules (food) from other organisms.

There are three types of heterotroph: **consumers, detritivores** and **saprotrophs**.

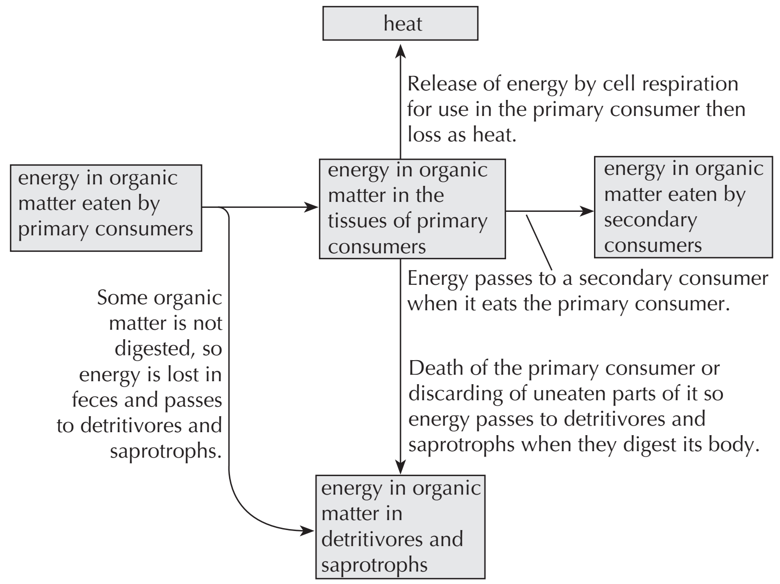
Consumers are organisms that ingest organic matter that is living or recently killed.
Primary consumers eat producers and so obtain energy from them. They do not absorb all of the energy in the food that they eat. The energy that they do not take into their tissues leaves them in one of three ways, shown in the flow chart (right). There are similar energy losses from secondary and tertiary consumers in the food chain. Locusts, sheep and lions are examples of consumers.

Detritivores ingest dead organic matter.
Dung beetles and earthworms are examples of detritivores.

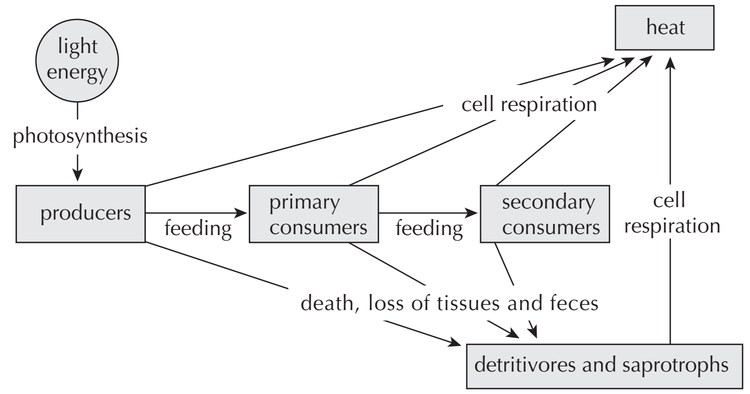
Saprotrophs live on or in dead organic matter, secreting enzymes into it and absorbing the products of digestion.
Bread mould and mushrooms are examples of saprotrophs.

The energy that passes to detritivores and saprotrophs is eventually released by cell respiration and lost as heat. In most communities all the light energy that was trapped by producers is ultimately lost as heat after flowing through the food chain.
A summary of energy flow for a three-stage food chain is shown (right).

Energy flow through consumers



Energy flow through a food chain

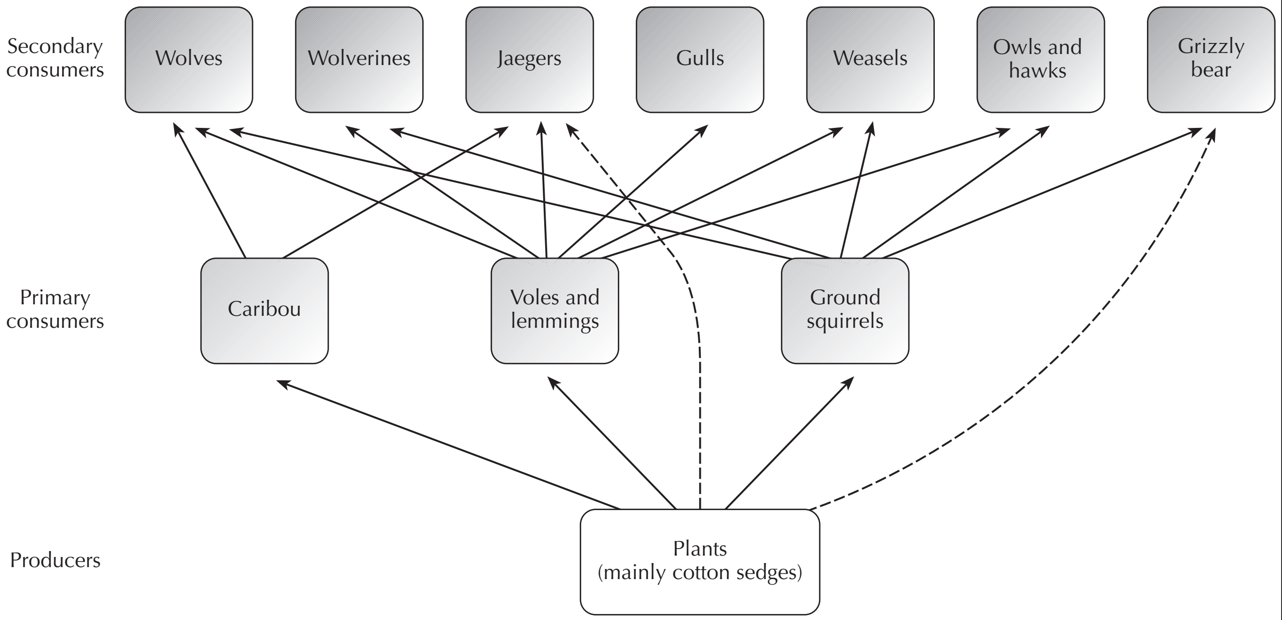


Food webs and energy pyramids

FOOD WEBS

A food web is a diagram that shows all the feeding relationships in a community. The arrows indicate the direction of energy flow. Complete food web diagrams are very complex. The figure (below) shows a simplified food web for a community that lives in an area of Arctic tundra in Ogotoruk Valley.

Food web for Arctic tundra



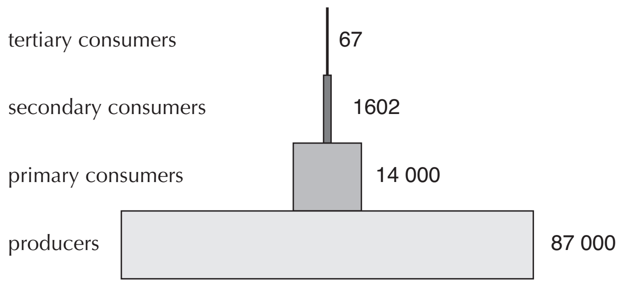
ENERGY PYRAMIDS

Energy pyramids are diagrams that show how much energy flows through each trophic level in a community. The amounts of energy are shown per square metre of area occupied by the community and per year ($kJ\,m^{-2}\,year^{-1}$).
The figure (right) is a pyramid of energy for Silver Springs, a stream in Florida.
The figure (below right) is a pyramid of energy for a salt marsh in Georgia. Pyramids of energy are always pyramid shaped – each level is smaller than the one below it. This is because less energy flows through each successive trophic level. Energy is lost at each trophic level, so less remains for the next level. Note that mass is lost as well as energy, so the energy content per gram of the tissues of each successive trophic level is *not* lower.
Energy is lost in various ways. In each of the first three ways the energy is not completely lost from the community as it passes to detritivores and saprotrophs.

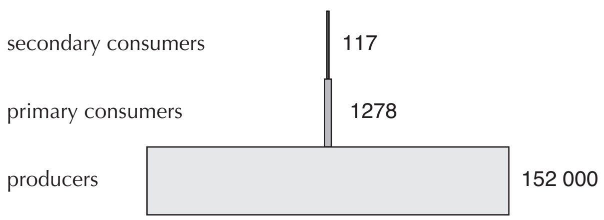
- Some organisms die before an organism in the next trophic level eats them.
- Some parts of organisms such as bones or hair are not eaten.
- Some parts of organisms are indigestible and pass out as feces.
- Much of the energy absorbed by an organism is released in cell respiration. The energy, in the form of ATP, is used in processes such as muscle contraction or active transport that require energy. These processes involve energy transformations, which are never 100% efficient. Some of the energy is converted to heat. 10–20% is a typical efficiency level. Most of the energy released by cell respiration is lost from the organism as heat.

Energy absorbed by living organisms is only available to the next trophic level if it remains as chemical energy in the growth of the organism. This is only a small proportion of the energy absorbed.

Energy pyramid for a stream



Energy pyramid for a salt marsh



Nutrient recycling

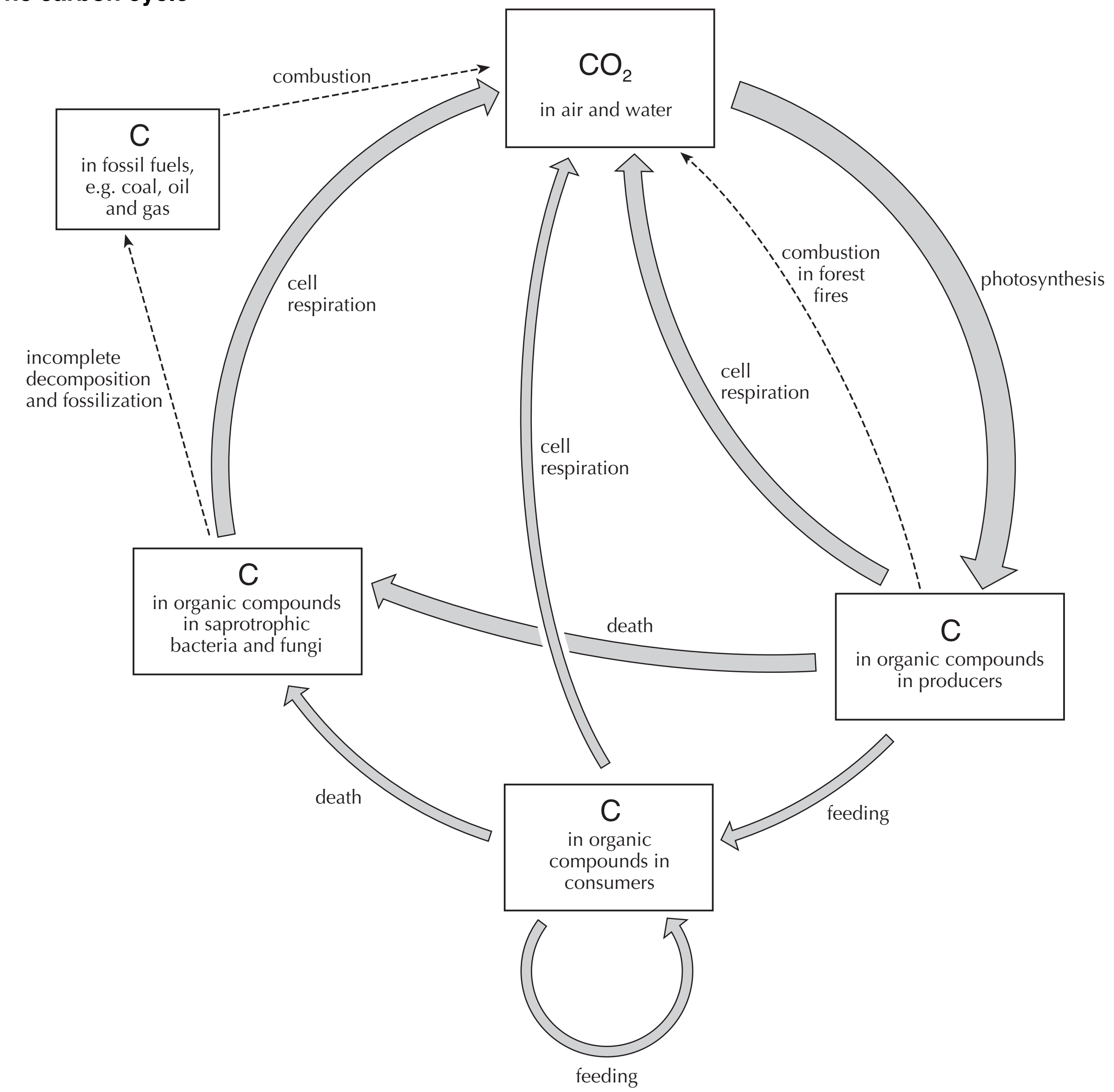
ECOSYSTEMS, ECOLOGISTS AND ECOLOGY

Communities of living organisms interact in many ways with the soil, water and air that surround them. The non-living surroundings of a community are its abiotic environment.
A community and its **abiotic environment** function together as a system called an **ecosystem**. *An ecosystem is a community and its abiotic environment.*
Ecologists study the complex relationships within ecosystems. This area of study is called **ecology**. *Ecology is the study of relationships in ecosystems – both relationships between organisms and between organisms and their environment.*

NUTRIENT RECYCLING IN ECOSYSTEMS

The recycling of nutrients is one example of the interactions between living organisms and the abiotic environment in an ecosystem. Energy is not recycled. It is supplied to ecosystems in the form of light, flows through food chains and is lost as heat. Nutrients are not usually resupplied to ecosystems – they must be used again and again by recycling. Carbon, nitrogen, phosphorus and all the other essential elements must be recycled. They are absorbed from the environment, used by living organisms and then returned to the environment.
The processes involved in the carbon cycle are shown below.

The carbon cycle



THE ROLE OF SAPROTROPHS IN RECYCLING OF NUTRIENTS

Saprotrophic bacteria and fungi have an essential role in nutrient cycles. They feed by secreting digestive enzymes into dead organic matter, including dead plants and animals and feces. The enzymes gradually break down the organic matter and the nutrients that were locked up in complex organic compounds are released. The saprotrophs absorb the substances that they need from the digested organic matter.
Without saprotrophs, nutrients would remain locked up permanently in dead organic matter and organisms that need the nutrients would soon become deficient.

Global warming and the greenhouse effect

RISING CARBON DIOXIDE LEVELS

The carbon dioxide concentration of bubbles of air trapped in Antarctic ice at different dates have been measured. These show that for two thousand years before 1880 the carbon dioxide concentration of the atmosphere remained fairly constant at about 270 parts per million (ppm).

From 1880 onwards the concentration rose. Since 1958, the concentration has been monitored continuously at Mauna Loa, Hawaii (right). There is an annual fluctuation, but the overall trend has been upwards and the concentration is now more than 100ppm higher than in 1880.

GREENHOUSE GASES

Carbon dioxide is one of a group of gases that cause heat to be retained in the Earth's atmosphere:

- carbon dioxide
- methane
- oxides of nitrogen (NOX)
- sulfur dioxide

Heat retention by gases is called the **greenhouse effect**. The processes involved are shown in the figure (right).

The greenhouse effect is not a new phenomenon. Natural processes produce greenhouse gases, so they are a natural part of the Earth's atmosphere. The change in recent years is that human activities have increased the production of greenhouse gases and so their atmospheric concentrations and their contributions to the greenhouse effect have been rising (below right). This is correlated with rising temperatures on Earth – **global warming**.

RISING GLOBAL TEMPERATURES

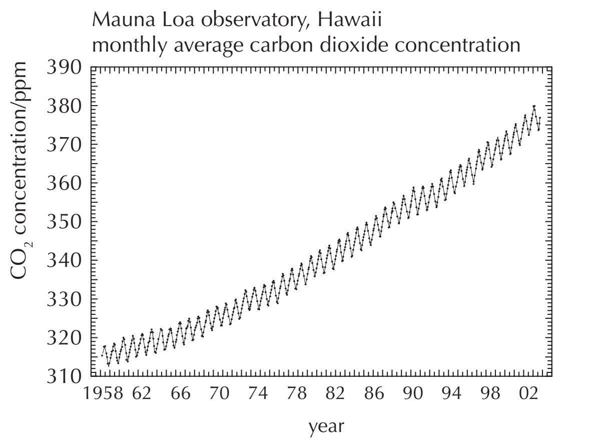
Temperature records have been analysed to find the mean for the whole world in each year from 1850 onwards. The figure (right) shows the difference between the mean temperature for each year and an overall mean temperature for the years 1961–1990.

The trends are that

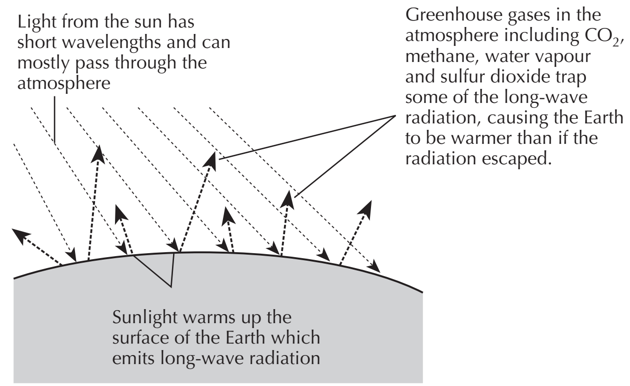
- From 1856 until about 1910 temperatures were relatively stable.
- From 1910 until 1940 temperatures rose and were then stable.
- From 1970 there has been a rapid rise.
- All ten of the hottest years since records began in 1850 have been since 1990.
- 1998 was the hottest year in that period and 2005 was the second hottest year.
- Over the past century, global temperatures have risen by 0.7°C on average, which takes us out of the range of average temperatures experienced on Earth over the last 1000 years.

These changes in temperature are statistically significant. There could be various causes, but the most likely cause is an increased greenhouse effect, due to human activities.

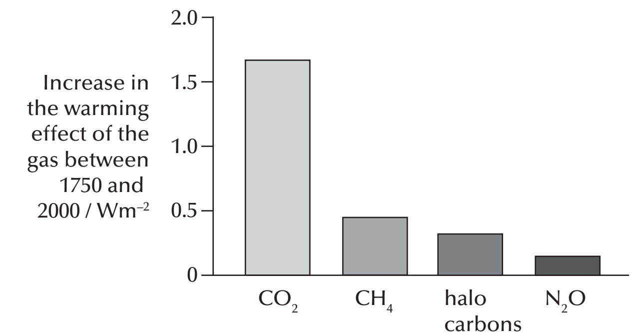
Graph of atmospheric CO_2 concentrations



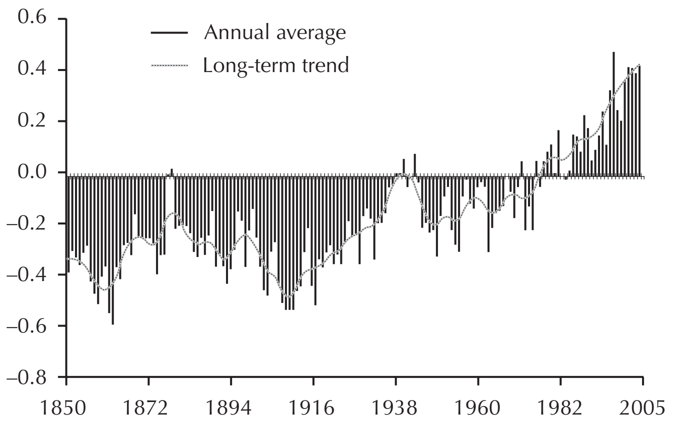
Cause of the greenhouse effect



Increases in effects of greenhouse gases



Annual global temperatures 1850–2005



Responses to global warming

HABITATS

The Earth provides places for millions of living organisms to exist. These places are called **habitats**.

A habitat is the environment in which a species normally lives or the location of a living organism.

CONSEQUENCES OF GLOBAL WARMING

The effects of global warming are already being felt, but they are likely to become much more extreme during the 21st century. Habitats throughout the world will be affected, but the effects on Arctic ecosystems could be particularly catastrophic.

- Glaciers will melt and polar ice sheets will break up into icebergs, which will also eventually melt. The Arctic ice cap may disappear completely.
- Permafrost will melt during the summer, increasing the rates of decomposition of trapped organic matter, including peat and detritus. This will cause release of carbon dioxide, further increasing atmospheric concentrations.
- Species adapted to temperate conditions will spread north, altering food chains and affecting animals in the higher trophic levels.
- Marine species of animal in Arctic waters may become extinct, as they can be very sensitive to temperature changes in seawater.
- Polar bears and other animals will lose their ice habitat, where they feed and breed.
- Pests and diseases may become more prevalent, with warmer temperatures.
- Sea levels will rise and low-lying areas of land will be flooded.
- Extreme weather events, such as storms, will become more frequent, with harmful effects on species that are not adapted.

THE PRECAUTIONARY PRINCIPLE

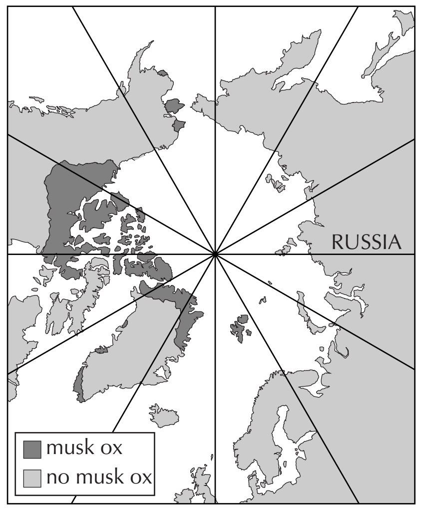
In a court of law, prosecutors try to prove that the defendant is guilty. If they cannot do this, the defendant is assumed to be innocent. When the precautionary principle is followed, the opposite policy is adopted – people planning to do something must prove that it will *not* do harm, before actually doing it. The precautionary principle should be followed when the possible consequences (risks) of human actions are very large or could even be catastrophic.

Although there is strong evidence that greenhouse gas emissions are causing global warming, there is no proof. Some politicians and business leaders have argued against measures to combat global warming, because it is not *certain* that greenhouse gases are causing it. Oil companies and airlines in particular have voiced opposition.

Many scientists have argued that if we waited for proof of the effects of greenhouse gas emissions before reacting, the consequences would probably have reached a catastrophic level. The risks are so great that the precautionary principle should be followed: anyone advocating continuing to emit greenhouse gases at current levels, or even to increase emissions, should be required to prove that this will not cause a damaging increase in the greenhouse effect.

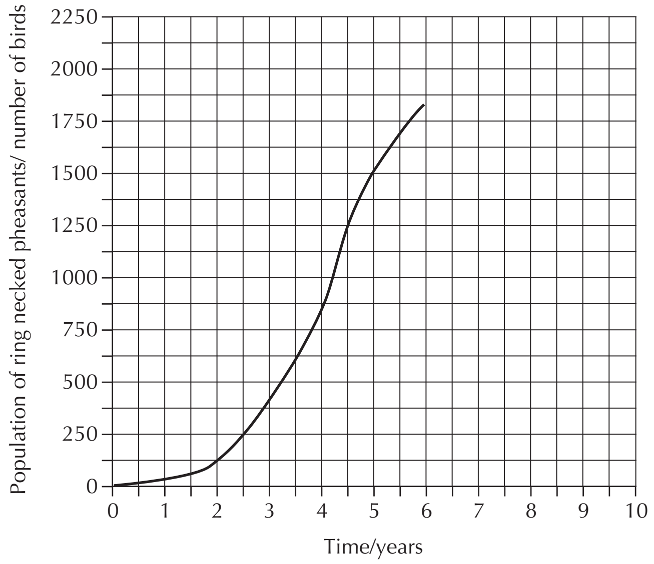
Ice sheet breaking up, with Greenland in the background

Musk ox (*Ovibos moschatus*) a species of mammal which nearly became extinct through over-hunting in the early 20th century. Protection by the Canadian government has allowed them to increase, with the population now over 60 000. They have a very thick coat and are adapted to the cold conditions of Arctic regions. The consequence of global warming for musk ox can be deduced from the distribution map (below).



Distribution map of musk ox in the Arctic

1 The graph below shows the growth of a population of ring-necked pheasants (*Phasianus colchicus*) on Protection Island off the north west coast of the United States. The original population released by the scientists consisted of two male and eight female birds. Two of the females died immediately after release.



[Source of data: Elinarson A. S., Murrelet, (1945) 26: pages 39–44]

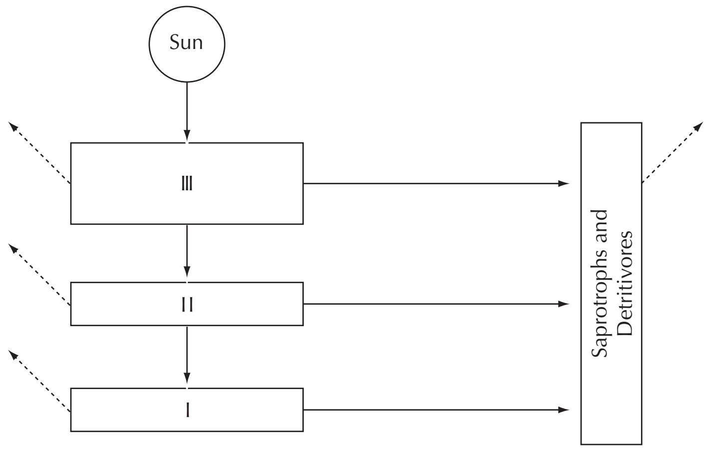
a) State the term used to describe the shape of a growth curve of this type. [1]

b) (i) The scientists predicted that the population would reach its carrying capacity of 2000 by year 8. Draw a line on the graph to show the population growth between years 6 and 10. [2]

c) (i) Predict how the population growth would change if all the female birds in the original sample had survived. [1]

(ii) Predict the effect on the carrying capacity if all the female birds in the original sample had survived. [1]

2 The diagram below shows in simplified form the transfers of energy in a generalized ecosystem.
Each box represents a category of organisms, grouped together by their trophic position in the ecosystem.



a) Deduce the trophic levels of the organisms in boxes I, II and III. [3]

b) State the form in which energy enters organisms in box 1. [1]

c) Identify which arrow represents the greatest transfer of energy per unit of time. (Add a large X to the arrow). [1]

d) Explain what is represented by the dotted arrows leaving each box. [3]

3 Methane acts as a greenhouse gas in the atmosphere. The main sources of methane are the digestive systems of cattle and sheep, bacterial action in rice paddies, burning of biomass (e.g. forest fires), bacterial action in swamps and marshes, burning of coal and release of natural gas.

a) Discuss whether methane emissions from these sources will cause a change in the Earth's temperature. [3]

b) Discuss whether release of methane is a natural process or an example of a human impact on the environment. [3]

c) Suggest measures that could be taken to reduce the emission of methane. [3]