The Wonderful Story of Living Things

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Contents

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CHAPTER 1

The conditions that allow life on earth

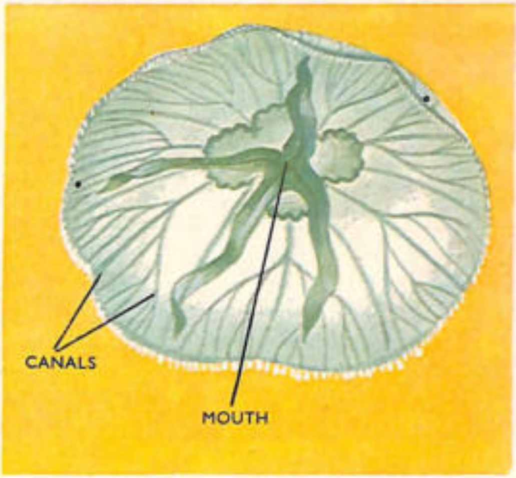
SCIENTISTS believe that life began on earth some 3,000 million years ago. Why did it start and what were the unique conditions that made it possible, and furthermore, for it to flourish?

Of the many substances that exist on earth water is probably the most important. In fact the lives of both animals and plants depend on it. One reason why water is essential to life is that animals and plants are mostly made of water. This is seen easily enough in a jellyfish which is nine-tenths water. Less obvious, but equally important, is the seven-tenths that makes up the human body. In fact an adult human contains eighty to ninety pints of water.

Over 70% of the earth is covered in water, the oceans accounting for most of this, though there are many rivers and fresh-water lakes.

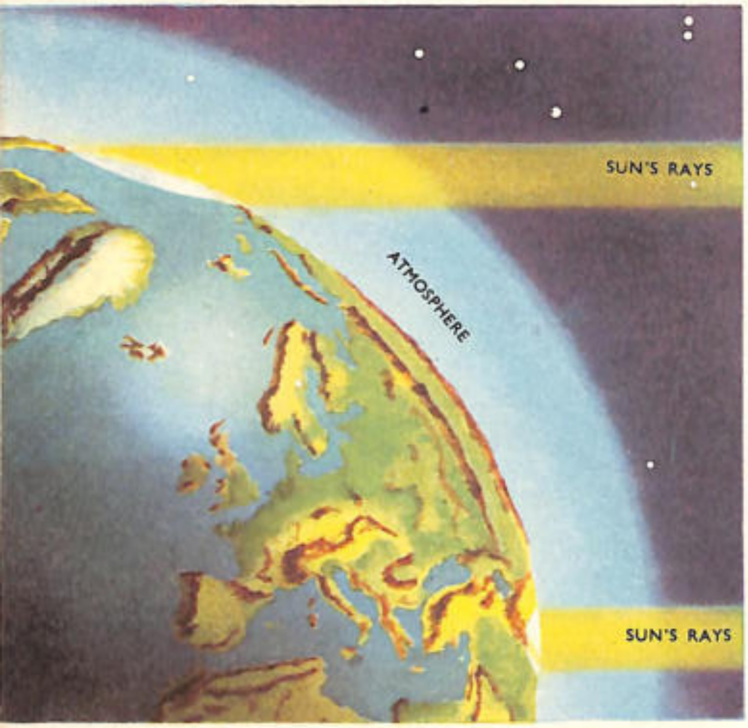
Water is important because of its unique properties. Most substances

More substances dissolve in water than in any other liquid. It is known as the universal solvent.



A jellyfish showing the elaborate system of canals through which fluid carrying food is circulated.

Over seven-tenths of the earth's surface is covered in water at an average depth of over twelve thousand feet.



Temperatures tend to decrease away from the equator, for in high latitudes a similar amount of the sun's rays is spread over a greater area than in low latitudes, and travels further through the atmosphere.

will dissolve in water. In fact water will dissolve more substances than any other. This is of tremendous importance to animals and plants. All the chemical reactions proceeding in living things take place in a watery solution. The chemicals themselves are dissolved in water. For example, the digestion of food in the gut of an animal takes place in a solution which is largely water, and the digested food passes in solution through the wall of the gut into the bloodstream. Solid food could not do this. Blood itself is a watery fluid. If the chemicals in the blood were not in solution the blood vessels would become clogged with solids and the flow of blood would be impossible. Similarly minerals and food substances could not move about in a plant if they were not in solution.

Water also loses and gains heat very slowly, slower than any other liquid. This means that in warm-blooded animals the blood can transport heat from one part of

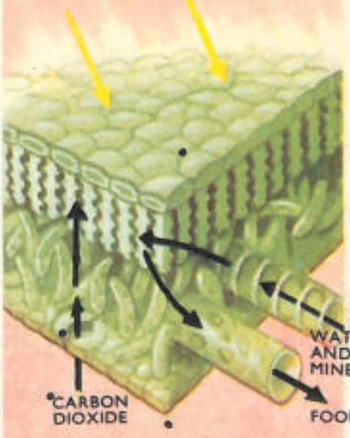
Continuously high temperatures and rain falling the whole year mean that the equatorial lowlands are virtual plant paradises.

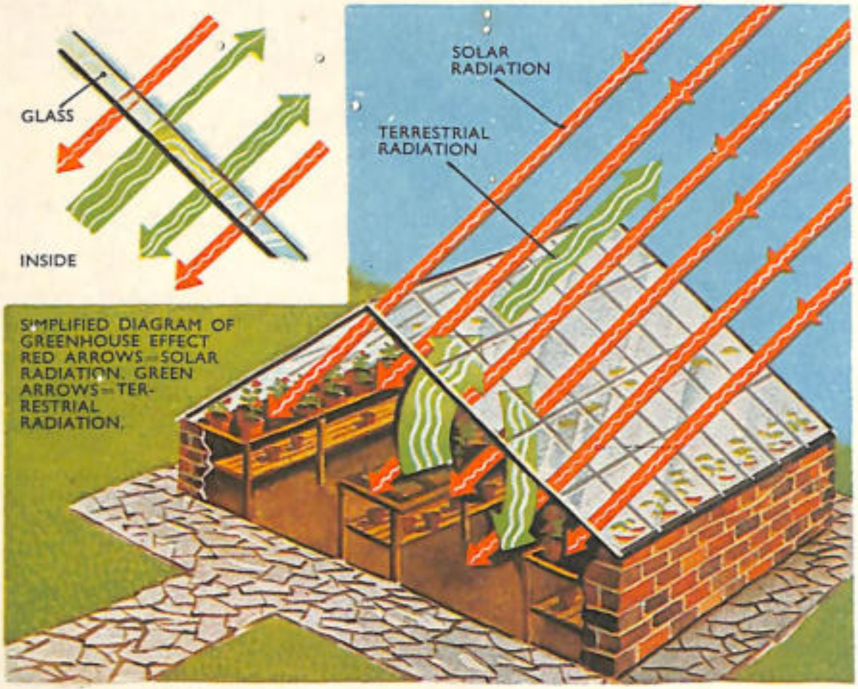
Conditions in the polar regions are very different from those of the equatorial regions. There is very little precipitation as rain or snow and the temperature rarely rises above freezing point. Animals such as Man could not exist there without artificial aids.

the body to another. Also, because the body contains so much water, its temperature will not be subject to rapid ups and downs. This applies to all living things. For this reason the vital chemical reactions going on within the body are not accelerated or slowed down to any great extent.

Water is also of great importance to plants and many animals because it gives them shape, blowing them out just as air does in a football bladder. We all know that pieces of seaweed go very hard and the bladders become very small when it is dry, but when the air is damp the bladders take in water and become swollen. Similarly, when flowers become short of water, as on a hot summer day, they become limp and wilt.

Oxygen is produced by green plants in their food-making processes by which water and carbon dioxide are used to make sugar using the energy of sunlight.



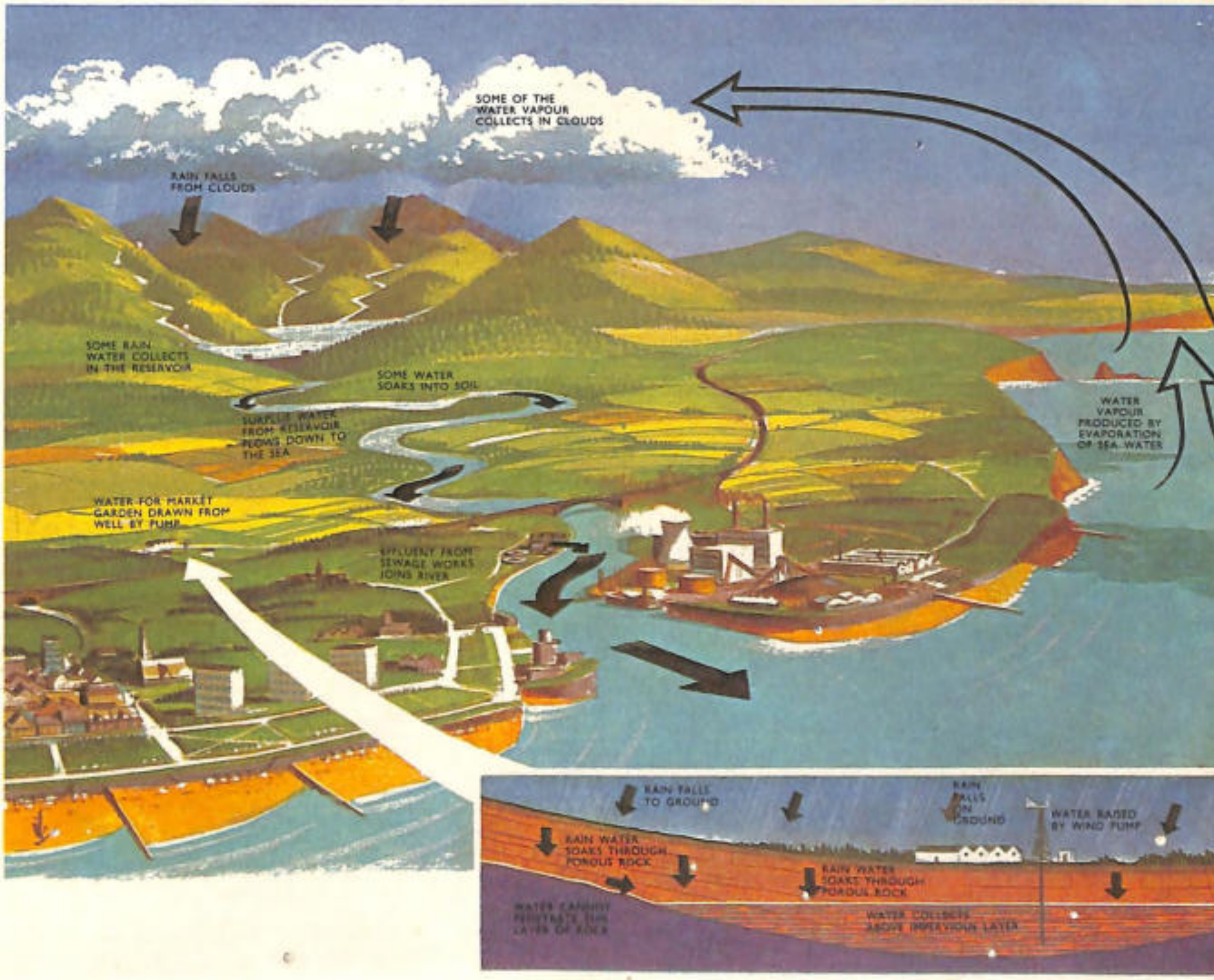


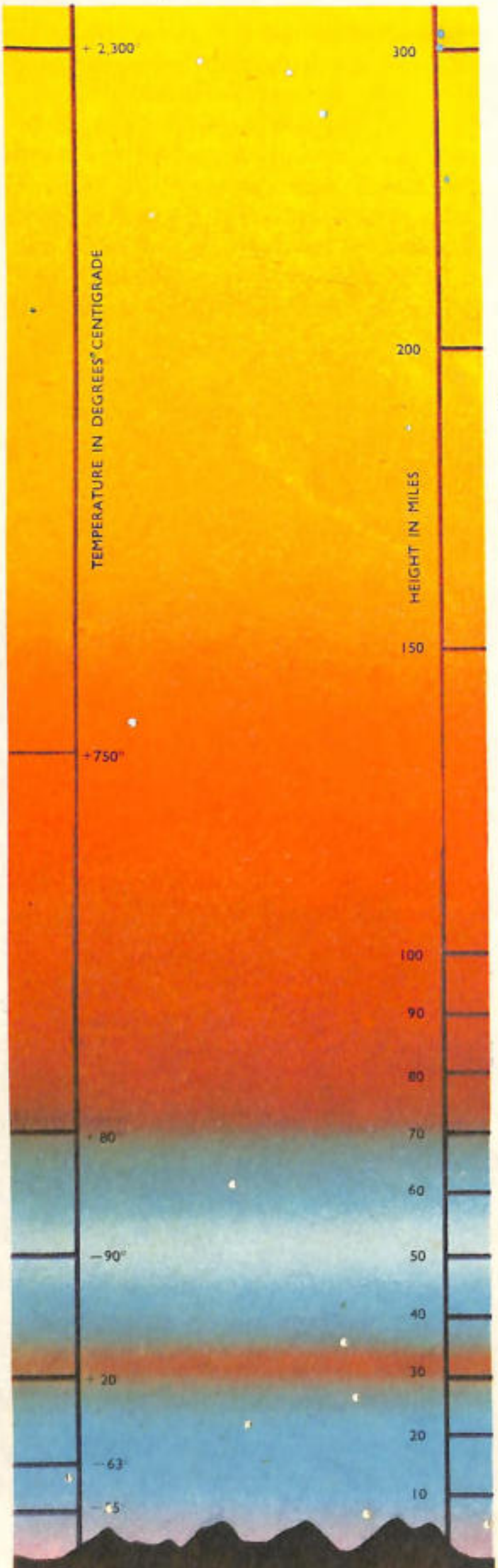
The greenhouse effect. By allowing the passage of solar radiation but absorbing some of the radiation emitted from plants and the ground and radiating part of it back, the glass of the greenhouse keeps the inside temperature higher than outside.

The atmosphere is also of vital importance to living things, for it acts as a shield during the day, protecting the earth from most of the sun's rays, and as a blanket at night, holding the heat in. Without it, the spinning surface of our planet would be alternately scorched by day and frozen by night; the temperature extremes would be too great for living things to exist. As it is, the atmosphere gives a greenhouse effect over the earth. A greenhouse allows most of the solar radiation to pass through it and be absorbed by the plants and ground inside. But the glass absorbs much of the energy re-radiated by the plants and the ground (because it is of a different wavelength) and sends part of it back into the greenhouse. In this way the temperature inside the greenhouse is kept higher than that of the surrounding air. The gases of the atmosphere, particularly water vapour, play a similar role to the glass in a greenhouse. They keep the temperature at the surface of the earth higher than outside the atmosphere.

The atmosphere not only minimises differences between day and night temperatures; it also tends to share out the heat received by different parts of the earth, making life possible nearly everywhere. The polar regions always receive less heat from the sun than equatorial regions, partly because a similar amount of solar radiation is spread over a greater surface area (due to the curve of the earth), and partly because the rays have to travel obliquely through a greater thickness of atmosphere before reaching the ground. This unequal heating is the basis of the world-wide motions of the air—the planetary wind system. At the equator heated air rises, lowering the pressure below and increasing it above. At the same time cold dense air over the poles sinks, increasing the pressure near the ground and lowering it above. In an attempt to even out these pressure differences, warm equatorial air flows polewards at high levels while cold air flows equatorwards at low levels. In practice the wind pattern is far more complicated than

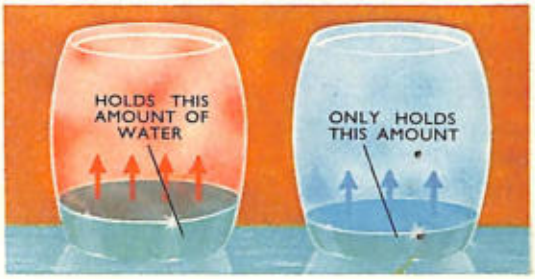
A simplified diagram showing the circulation of water in nature. Air passing across the sea picks up water vapour by the evaporation of the water. As it crosses land it may be forced to rise which may ultimately result in some of the vapour condensing to water droplets and falling to the ground as rain. Some of this will eventually find its way back to the sea again in rivers and streams. It is this continual cycle that makes the land such a good region for animals and plants to live in.





◀ The atmosphere is a transparent envelope of gas, hundreds of miles thick, surrounding the earth and held to it by gravity. Without it life as we know it could not exist. Not only would there be a complete absence of oxygen but the direct rays of the sun would sear the earth during the day, while at night temperatures would fall far below freezing point. It acts as a protective shield during the daytime and as a blanket at night to hold the heat in. This diagram shows the temperatures in the atmosphere.

The atmosphere acts as a protective envelope cutting off much of the sun's harmful radiation.

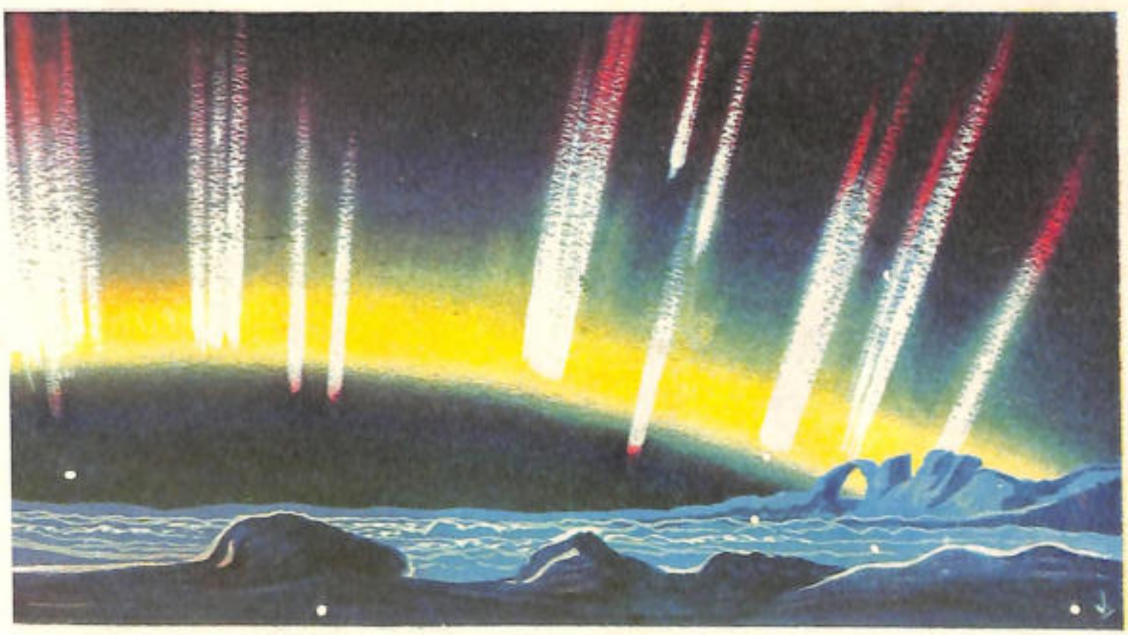


The fact that air can hold water in the form of vapour is vital to the formation of clouds and rain. But the amount of water air can hold in the form of vapour (and hence the amount of rain it can bring) increases with its temperature. This partly explains why regions of the land close to cold water (which chills passing winds) are often deserts. Conversely, winds blowing off warm seas on to land carry large quantities of moisture. Those passing over the Gulf Stream deposit much rain on Western Europe.

this — it is affected by the spin of the earth, for instance, and the varying rates at which land and sea areas heat up and cool down.

Winds fulfil another vital function, apart from spreading the heat; they alone are responsible for bringing water to the land. As a body of air moves across the sea it picks up water evaporated from the surface. Later it may cross the land and be forced to rise, perhaps by high ground lying in its path. Rising air expands, and expanding air cools. Since the amount of water vapour air can hold depends upon its temperature, some of the vapour will eventually condense back to water droplets (or ice crystals), forming cloud. If the droplets grow heavy enough to beat ascending air currents, they will fall to the ground as rain (or snow), most of which will find its way back to the sea ultimately through streams and rivers. In other words, there is a continuous circulation of water between the sea and the land which provides the moisture so necessary to terrestrial plants and animals.

The aurora borealis, or northern lights, is due to radiation from the sun exciting gases (probably nitrogen and oxygen) in the upper layers of the atmosphere.



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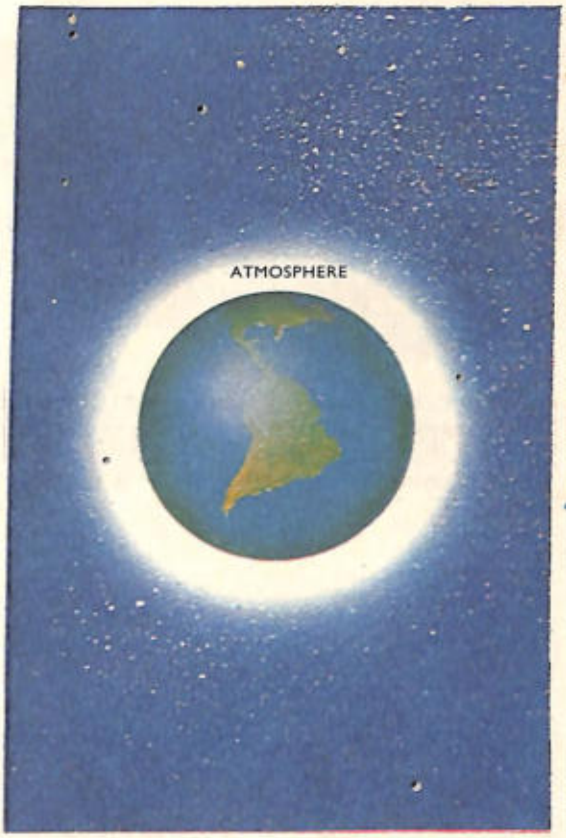
The atmosphere is a mixture of gases, consisting mainly of nitrogen (about 80%) and oxygen (about 20%) with minute traces of carbon dioxide and inert gases such as argon, neon and helium. Nearly all plants and all animals have to take in oxygen gas for the chemical processes, such as growth, going on within their cells.

But where did the oxygen come from? The large amounts of free oxygen upon which our lives depend were mainly produced after green plants appeared on the land, for these take in carbon dioxide and produce oxygen in their food-making processes known as photosynthesis. As time went by the amount of oxygen in the atmosphere grew steadily. This led the way for the evolution of air-breathing animals.

The atmosphere has been like it is today for millions of years, but its present composition is by no means securely fixed. It relies upon a very delicate balance of nature. Plants,

Most of the ultra-violet radiation from the sun is absorbed by the lower atmosphere. A little ultra-violet light is beneficial, causing 'sun-burn', for example. Man creates his own ultra-violet light for a wide variety of uses, particularly for killing bacteria, as in the preparation of drugs, which must not be contaminated by bacteria.

The earth's gravitational pull holds the atmosphere in place and prevents it from flying off into space. The moon has no atmosphere because its gravitational pull is so small. Without gravity objects have no weight. The atmosphere pushes down on us with a force of fifteen pounds per square inch. Our bodies are adapted to withstand pressures of this order.



for instance, replenish the oxygen in the air because they produce more oxygen in their food-making processes than they need for respiration (the chemical processes going on within their cells). Animals need the oxygen for their own internal workings and they themselves produce carbon dioxide that plants need for their food-making processes. If all the green plants in the world were to die there would be very little oxygen left in the atmosphere in a very short time.

Another important function of the atmosphere is the absorption of other, harmful kinds of radiation such as cosmic rays and X-rays. If large amounts reached the surface no life could exist. Planets without an atmosphere could not support life. The attractive displays sometimes to be seen in the sky, particularly in high latitudes, the auroras, are in fact due to radiation from the sun exciting gases (probably nitrogen and oxygen) in the upper layers of the atmosphere.

The crystals of four salts (from left to right): wulfenite – lead molybdate, stibnite – antimony sulphide, malachite – copper carbonate, and tourmaline – a silicate. Some living things look just like crystals, and a crystal suspended in a salt solution will grow, but it cannot reproduce and it is insensitive. It is therefore non-living.

CHAPTER 2

Living or non-living?

IT IS not known what life is. But we are certainly able to tell the difference between a rock, which is non-living, and a butterfly or a tree which are alive. As to what it is that makes one thing living and another non-living we have yet to discover. It is difficult to define living and non-living. There are some things on the borderline between living and non-living things. Living things grow. But this is not a distinguishing character on its own for a crystal suspended in the appropriate salt solution will also get larger. On the other hand most non-living things do not grow. Some living things look very much like crystals. Certain viruses, for example, can be crystallised but afterwards they will infect another living thing and will start to grow and reproduce. Reproduction is one of the most characteristic features of living things.

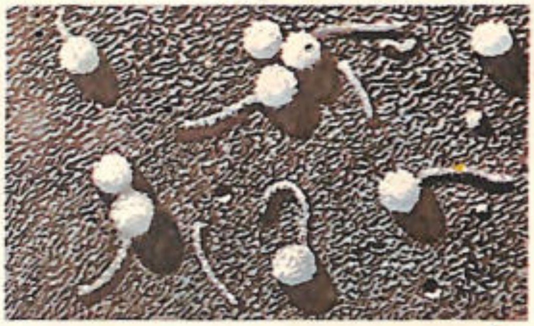
A fish does not dissolve in the water in which it lives. If a lump of sugar which is non-living is dropped into a glass of water it will dissolve. These obvious statements sum up another characteristic of living things. In order to remain distinct from the things around it an animal, and a plant too, have to expend large amounts of energy. It obtains this energy from the food that it eats. A large part of each day is directed towards finding and consuming food. Feeding is another characteristic of living things.

Living things are also sensitive to

the things around them. An *Amoeba* will move away from an unpleasant stimulus; an earthworm will slither back into its burrow at the approach of a bird, and even a plant such as a tree will bend towards the light. Its roots too will grow towards water. Non-living things show none of these responses.

Apart from the simplest living things such as viruses all living things from the simplest single-celled creatures upwards are composed of cells. The basis of all living cells is protoplasm. It is important to realise that this is not a single substance, but a very complicated mixture of chemical substances in which chemical changes are continuously taking place. Its composition therefore not only varies between different kinds of animals and plants but in individuals between cells performing different tasks. A heart cell is very different from a nerve cell.

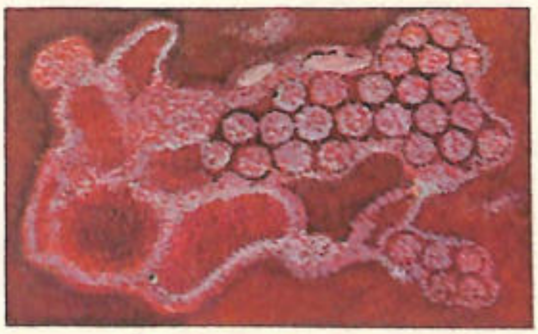
The main component of protoplasm is water in which there are suspended or dissolved many substances such as proteins (of which meat is mainly composed), lipids (these are fatty substances) and mineral salts.



This bacterial virus only attacks bacteria. It has been photographed with the electron microscope and is here shown magnified many thousands of times.

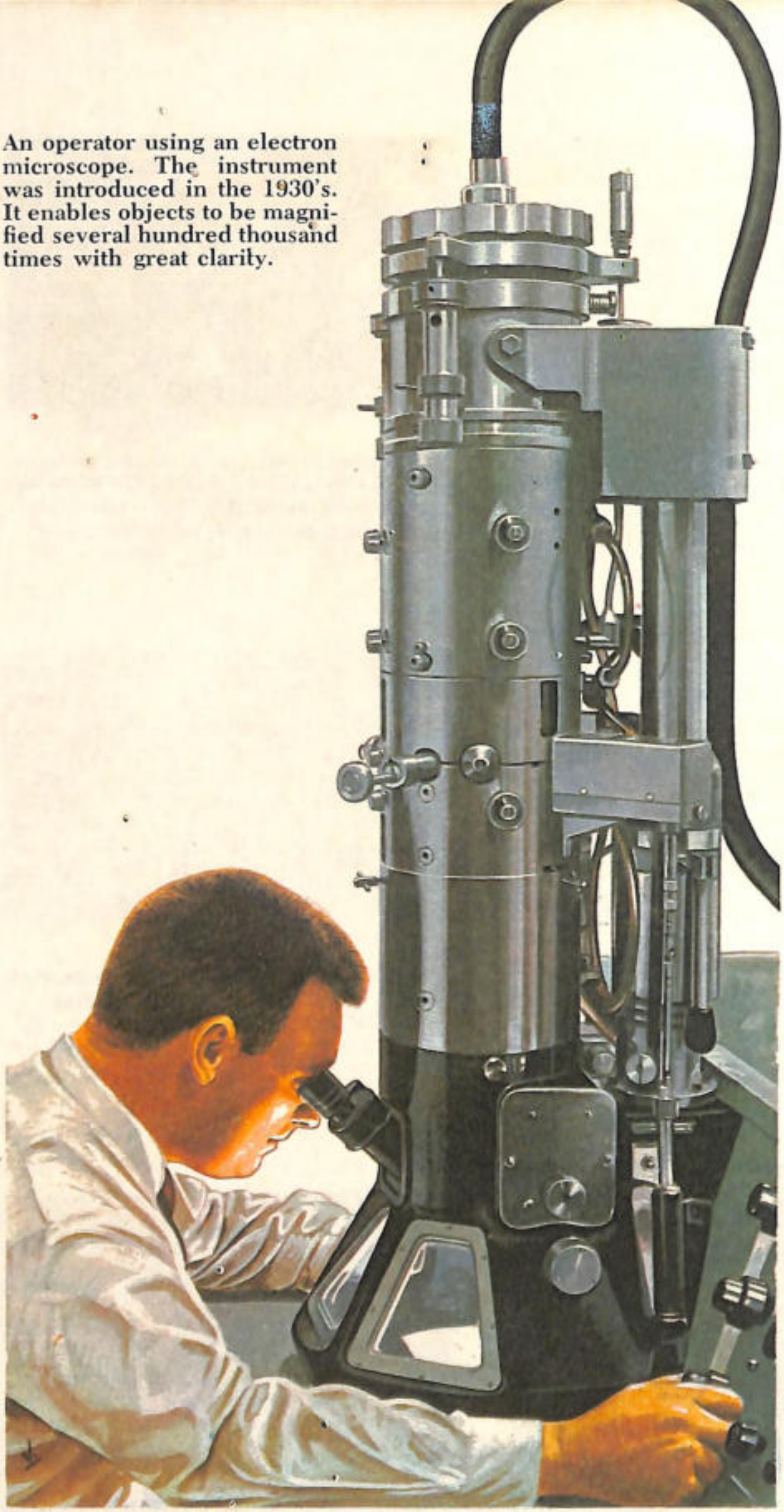
Aucuba mosaic viruses are like long, thin fibres. They cause a mosaic disease in tomato plants.

Tobacco mosaic viruses are rod-shaped structures about one four-thousandth of a millimetre long, here shown magnified about thirty thousand times.

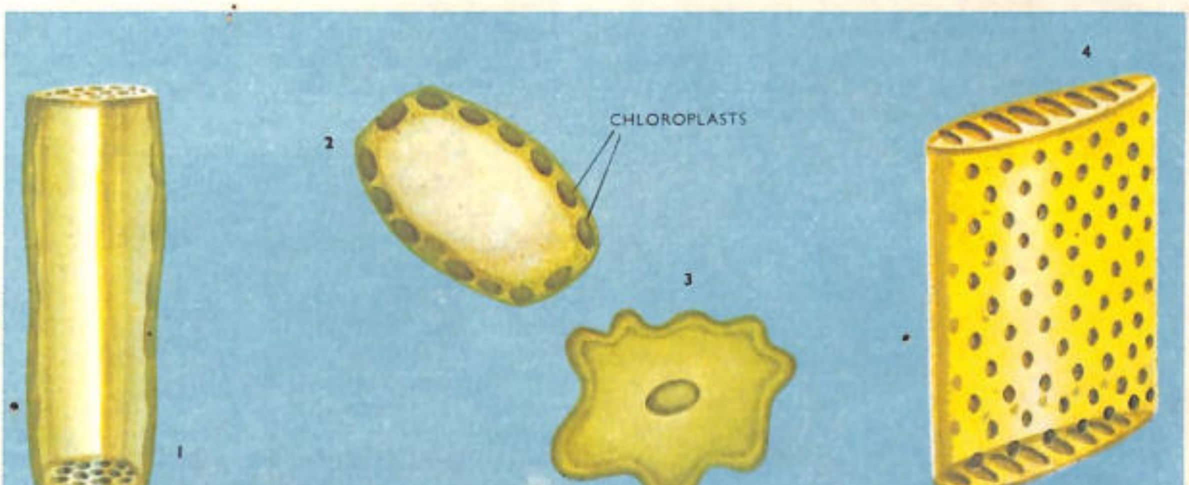


Poliomyelitis virus particles, magnified many thousands of times, shown inside an infected cell.

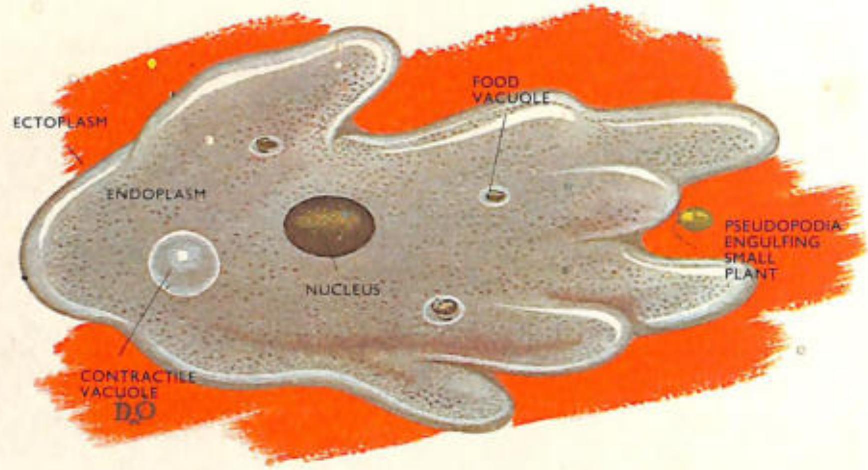
An operator using an electron microscope. The instrument was introduced in the 1930's. It enables objects to be magnified several hundred thousand times with great clarity.



A diagram of half a cell showing the amount of detail which has been discovered using the electron microscope. Figure (1) indicates the large, central nucleus which contains the hereditary instructions, (2) the mitochondria—sausage-shaped and spherical structures on which the enzymes are arranged, (3) the Golgi apparatus named after its discoverer but whose function is not surely known, and the lacy network of canals that ramifies through the part of the cell surrounding the nucleus and which is known as the endoplasmic reticulum. Its function is not known, and it was only discovered by the use of the electron microscope.



Four types of cell found in flowering plants. (1) A stem cell through which food passes from one part of the plant to another. (2) A leaf cell in which food is made in spherical bodies called chloroplasts. (3) A cell that forms part of the outer skin of a leaf, and (4) a stem cell that passes water to the leaves.



Amoeba is a relatively simple one-celled creature that lives in water. It is able to move about, to feed, to grow and to reproduce itself. Food is surrounded by projections of its protoplasm called pseudopodia and a food vacuole is formed in which the food is digested by the action of enzymes. The contractile vacuole is a device for getting rid of water surplus to the amoeba's requirements.

The very detailed structure of a cell has only been revealed in the last few years with the discovery and development of the electron microscope. This instrument can magnify cells several hundred thousand times, and more important it can distinguish clearly between tiny structures that are very close together. This enables us to see the structure of

The coral animal is a more complicated many-celled animal with tentacles equipped with special stinging cells for catching food and for defending itself. It makes a small limestone cup into which it is able to withdraw when it is not feeding. Corals that live in colonies often build huge reefs with their skeletons.

Two types of protozoans (single-celled animals) with rather more complicated structure than that of _Amoeba_. (above) _Paramecium_, an inhabitant of freshwater ponds and the like: (below) _Euglena_, a tiny freshwater creature on the borderline between animals and plants.

If an amoeba has plenty of food it grows rapidly before, on reaching a certain size, it must divide into two. First the nucleus divides, then the rest of the cell. This method of reproduction is called binary fission.

the cell in very great and clear detail. Apart from the protoplasm almost all living cells have one structure in common, the nucleus. This governs what happens in the rest of the cell. As a rule there is only one nucleus in each cell. The surrounding protoplasm has within it a complicated system of canals (endoplasmic reticulum) like a rather elaborate underground railway network, together with other structures (mitochondria) that carry chemicals called enzymes which promote the chemical changes proceeding in the various parts of the cell, including the growth of new parts.

The electron microscope is similar in principle to the ordinary light microscope except that it uses electrons instead of light and the system of lenses is a series of magnetic fields.

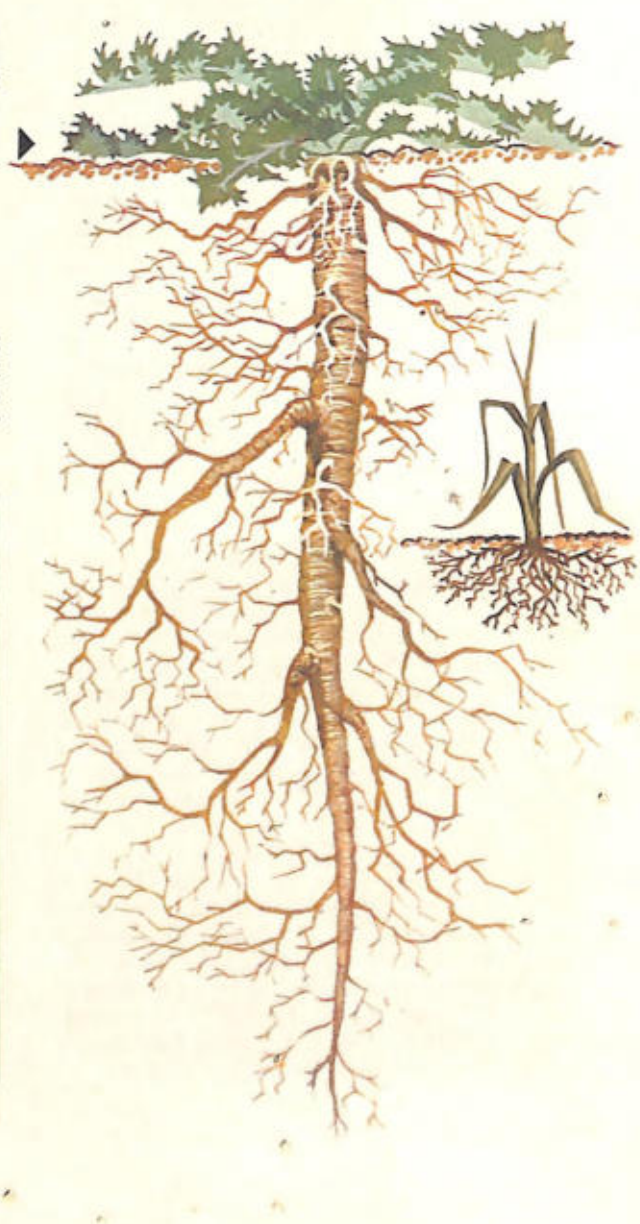
The illustrations show a few of the many different kinds of cells that are to be found in human beings. Other animals, such as anemones and corals, also have muscle cells and nerve cells though the details of these differ from human cells.

The cells of an animal's body are to be found in many shapes and sizes depending on their role in the body, though even cells of a particular kind, such as a nerve cell, also show great variety of shape. The cells indicated here are as follows: (1) a single nerve fibre, (2) a group of muscle fibres, with striped fibres uppermost and smooth or unstriped fibres beneath, (3) red blood corpuscles—these carry oxygen from the lungs to the tissues, (4) two types of blood corpuscle—some of which form part of the body's defence mechanism against disease-causing organisms, (5) lining or epithelial cells from the windpipe—these are equipped with cilia that beat to remove a film of slime from the lungs carrying dust particles and any other unwanted matter.

CHAPTER 3

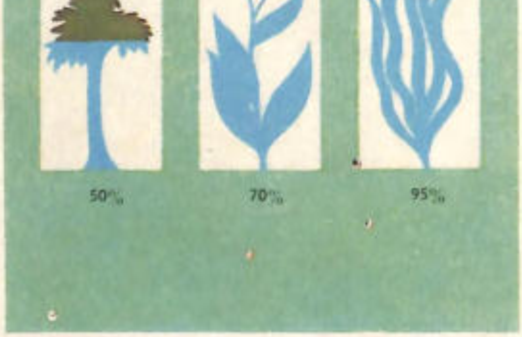
Plants in their surroundings

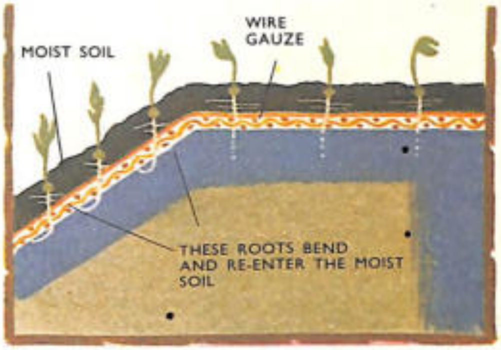
PLANTS occur in great numbers both in the sea and on land. Obviously conditions in these two environments are very different. But the basic processes going on in all plants are basically the same. We have seen in an earlier chapter how water is of tremendous importance to a plant and indeed to animals as well. In a water-dwelling plant there may be as much as ninety-five per cent water and even in a tree which one might regard as being solid wood there is fifty per cent of water. A plant

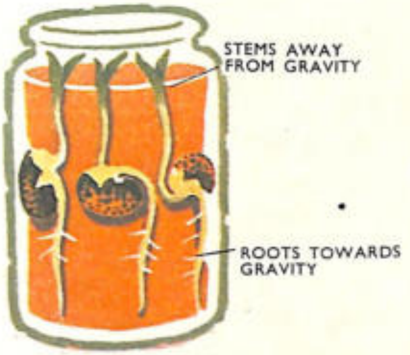


The two main kinds of root system in flowering plants, (far right) the fibrous root system of a grass, and the tap root of a thistle. Roots anchor a plant in the soil and also probe for water and mineral salts which the plant requires for its food-making processes.

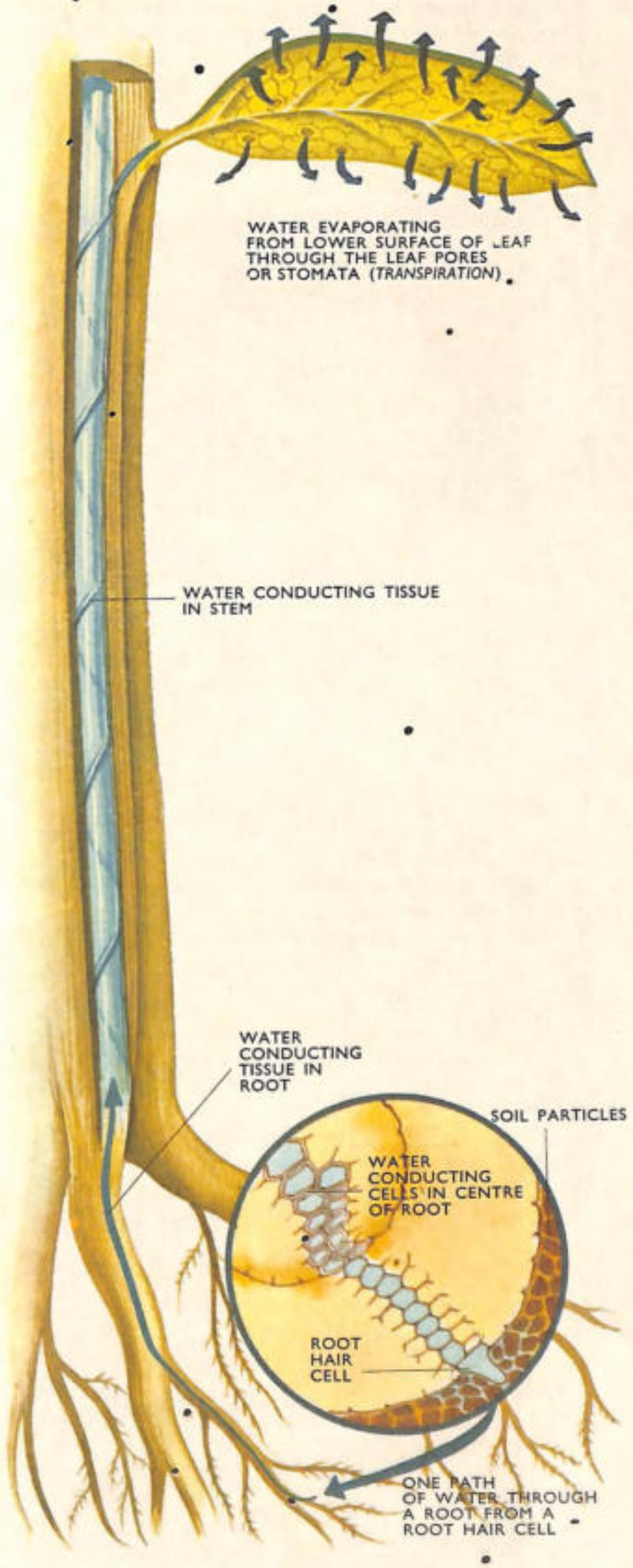
A tree (left) contains about fifty per cent of water by weight, (centre) a herb about seventy per cent, and (right) a water-dwelling plant as much as ninety-five per cent.





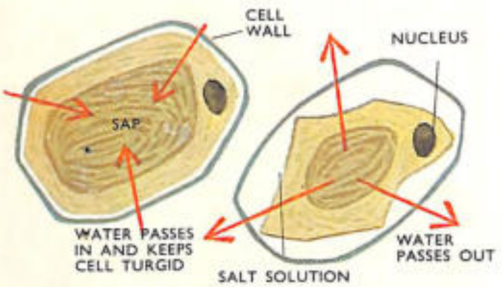


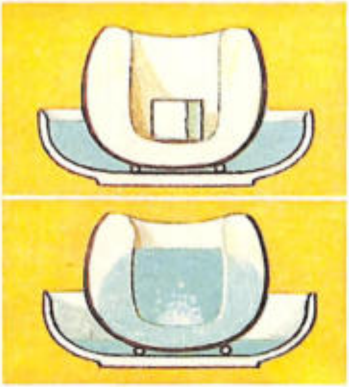
The roots of a plant are very sensitive to water and they will grow towards it. They are also responsive to gravity and normally grow downwards under its influence. But this influence may be overruled by the influence of water, and roots which have been growing downwards normally will curve upwards if there is no moisture below and if there is a source of moisture above.



A diagram showing a path of water from the soil into a root hair cell (inset) and up the water-conducting tissues of the stem to the leaves, where some evaporates through the leaf pores.

A young plant cell cut away and showing schematically the movement of food materials (spirals) through the watery protoplasm. Enzymes are piecing together some molecules and splitting others. Mineral salts are shown as red, green and yellow blobs, and the nucleus is the large, central blue structure.



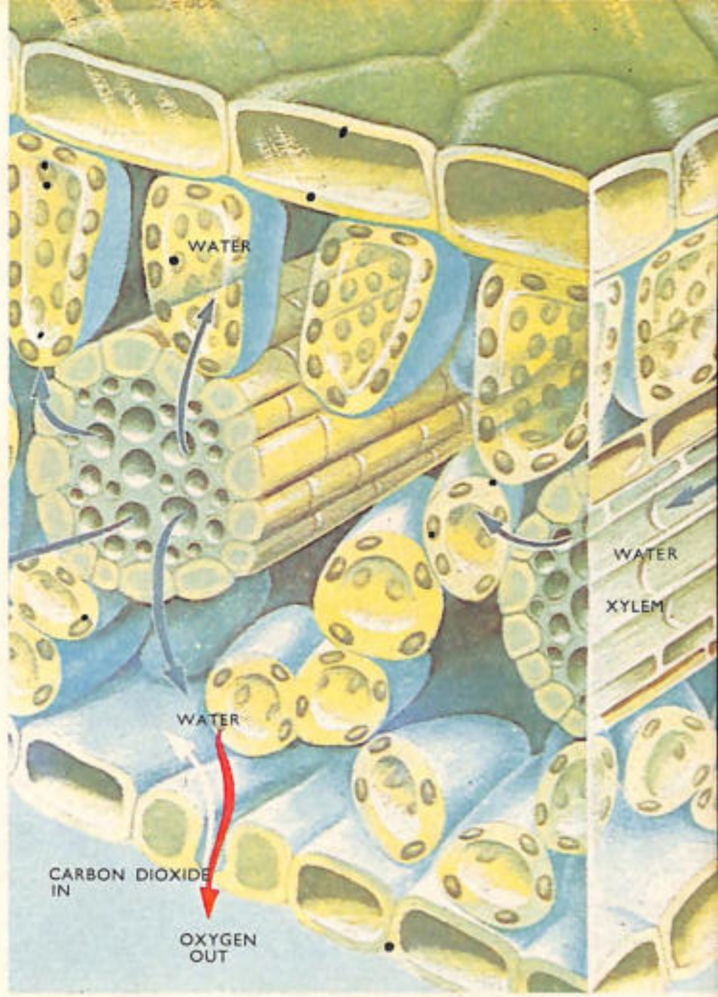


An experiment to show osmosis. A lump of sugar is placed in a hollowed-out, peeled, raw potato, standing in a saucer of water. Water is gradually drawn up through the potato and can be seen filling the hollow. The potato acts as a semi-permeable membrane. Cells behave in a similar way. A cell placed in pure water swells because water enters by osmosis, but one placed in strong salt solution shrivels up because it loses water.

in the sea or in a lake or a river obviously has little difficulty in obtaining water, but on land the story is a very different one and it is not surprising that plants expend so much energy in obtaining it. Even a small plant such as a dandelion or a thistle may have roots reaching one or two feet down into the ground, and the branching roots of a tree may spread through the soil for several hundred feet. The roots of a plant are very sensitive to water and they will grow towards it. They are also responsive to gravity and normally grow downwards under its influence. But this influence may be 'over-ruled' by the influence of water, and as the illustration shows roots which have been growing downwards normally will curve upwards if there is no moisture below and if there is a source of moisture above.

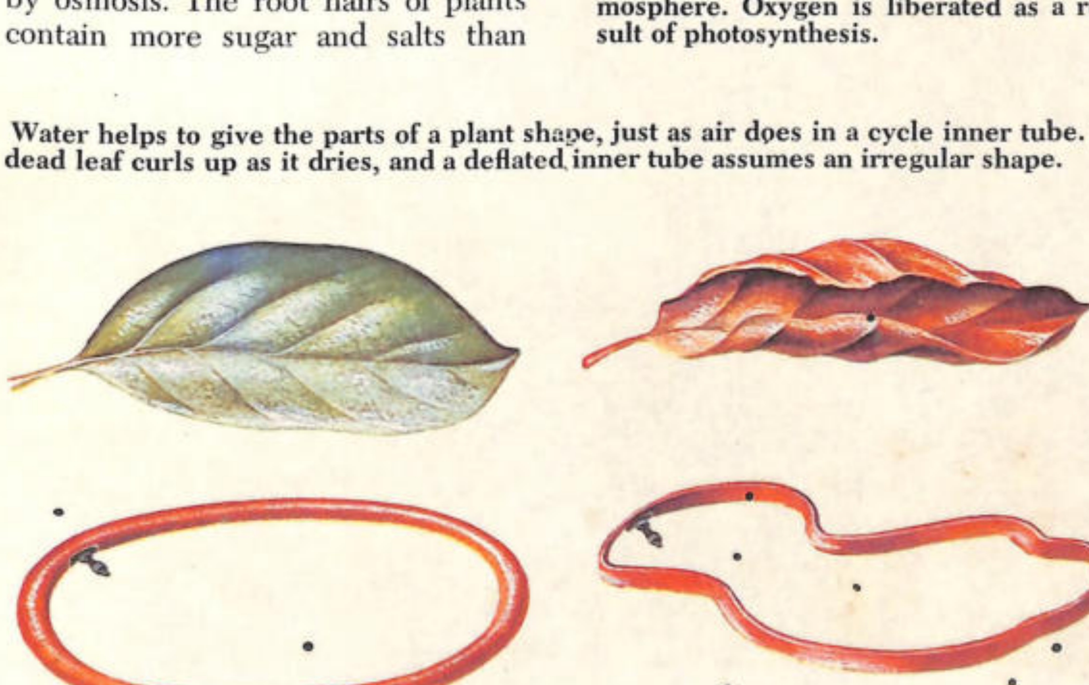
As plants have evolved, special tissues have developed in the more advanced forms for the transport of water from one part of the plant to another. The mechanism by which water is raised up the stem of a plant to the leaves is not fully understood, but nevertheless it reaches the leaves of a tree more than three-hundred feet high.

Plants take up water from the soil by a process called osmosis. The experiment shows how osmosis works. Part of a potato is hollowed out and a lump of sugar is placed in the hollow. The potato is placed in a beaker that has some water in it. After a time water is drawn up through the potato into the hollow by osmosis. The root hairs of plants contain more sugar and salts than



A block diagram of part of a leaf showing the movement of water through the conducting channels, the inward passage of carbon dioxide for photosynthesis, and the outward flow of oxygen into the atmosphere. Oxygen is liberated as a result of photosynthesis.

Water helps to give the parts of a plant shape, just as air does in a cycle inner tube. A dead leaf curls up as it dries, and a deflated inner tube assumes an irregular shape.



A water culture experiment, by which the mineral requirements of a plant can be investigated. The control pot contains all the minerals necessary for healthy growth and the plant grows normally, but plants growing in pots that lack one substance show deficiency diseases characteristic for each deficient substance.

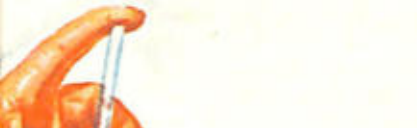
the water in the soil so that water enters the root hairs by osmosis and eventually passes into the water conducting vessels in the centre of the root. All the food substances that a green plant makes in its leaves pass from there to other parts of the plant

in a watery solution. Similarly the mineral salts that enter the roots of a plant from the soil also pass through the plant in solution.

The presence or absence of certain minerals from the soil can have a serious effect on the way in which a plant grows. Scientists have been able to grow plants in the laboratory under very strict conditions and have shown what the effect of certain mineral deficiencies are. As you can see in the picture, the control jar which has all the substances that a plant requires for healthy growth contains a very healthy plant. The other jars which each have one substance missing show plants in various stages of stunted growth.

Oat seedlings are commonly used in growth experiments. This experiment shows, by covering or removing the tip, that the latter controls movement in response to light. Only the normal seedling bends over towards the light.

Light is also of great importance to green plants, for they use some of the energy in it in their food-making processes. Plants grown in the dark are not able to make their own food, and they become tall, thin and very pale due to the lack of chlorophyll (the green colouring matter).

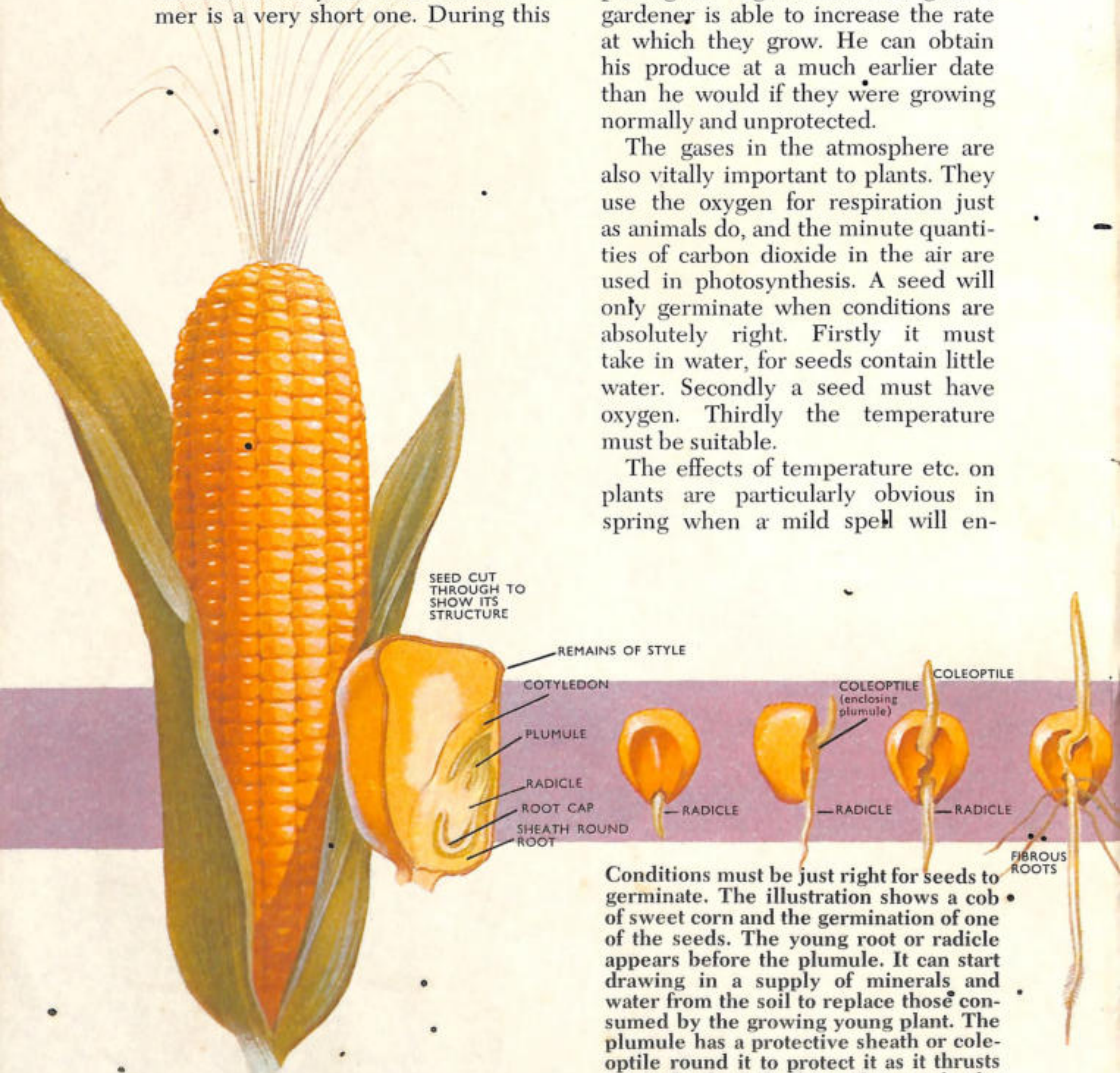


By placing his vegetables under glass a gardener is able to increase the rate at which they grow. He can obtain his produce much earlier in the year than he would if they were growing normally and unprotected.

The temperature at which plants grow also affects their growth considerably. For example in the colder, Arctic regions of the world plants are only able to grow in about two months of the year. The Arctic summer is a very short one. During this time they have to complete their whole life cycle. In contrast in the tropics there are no seasons. Conditions are warm throughout the year and plants grow continuously. By placing his vegetables under glass a gardener is able to increase the rate at which they grow. He can obtain his produce at a much earlier date than he would if they were growing normally and unprotected.

The gases in the atmosphere are also vitally important to plants. They use the oxygen for respiration just as animals do, and the minute quantities of carbon dioxide in the air are used in photosynthesis. A seed will only germinate when conditions are absolutely right. Firstly it must take in water, for seeds contain little water. Secondly a seed must have oxygen. Thirdly the temperature must be suitable.

The effects of temperature etc. on plants are particularly obvious in spring when a mild spell will en-



Conditions must be just right for seeds to germinate. The illustration shows a cob of sweet corn and the germination of one of the seeds. The young root or radicle appears before the plumule. It can start drawing in a supply of minerals and water from the soil to replace those consumed by the growing young plant. The plumule has a protective sheath or coleoptile round it to protect it as it thrusts upwards through the soil towards the light.

Plants are often covered in dew. Water vapour in the cold night air condenses on them.

courage the vigorous growth of bulbs, which seem to appear from nowhere.

Over millions of years through the processes of evolution plants have become more and more adapted to the conditions around them. Even wind currents are of considerable assistance. Plants such as hazel rely on the wind to distribute the pollen from their yellow catkins. Others such as sycamore, dandelion and thistle rely upon wind to carry their winged or plumed fruits to some distance from the parent plant to new ground.

Hazel catkins swaying in the wind scatter pollen onto the red stigmas of the female flowers. Many plants rely on the wind for pollination, and those such as sycamore, dandelion, willow herb and poppy rely on it to carry their fruits away from the parent plant.

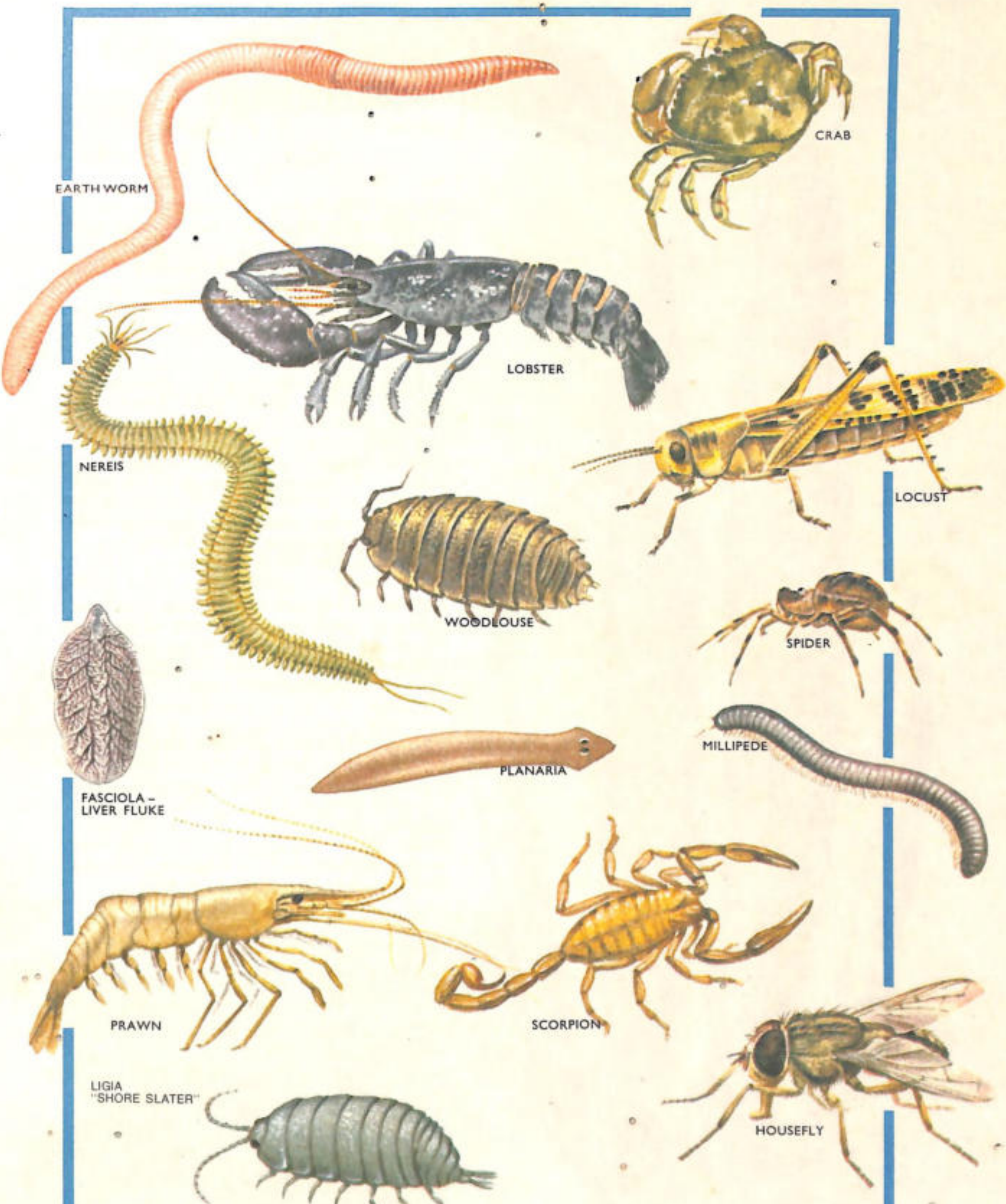
CHAPTER 4

Animals in their surroundings

THERE are around a million and a half different kinds or species of animals. The majority of these live on land, but there are still incredible numbers living in the sea. So many in fact that at times they colour the water. The Red Sea is so named because of the occurrence from time to time of millions of tiny red animals. Unlike plants which are restricted to the sunlit upper layers of the sea, animals inhabit all parts, from the surface water to the deepest abyss and from tropic to pole. The problems that animals have to face in their differing surroundings are obviously very different. Water is by far the easiest environment in which to live for the conditions within it are far more constant than those on land. The water temperature of the English Channel varies far less from winter to summer than the land on either side. This is because water gains and loses heat very slowly compared with the land.

Animals living in water have all the water that they need. An animal on land has not only to find sufficient water but also to conserve it. Hence many animals living on land spend as much time as possible in damp, shady situations. An earthworm only emerges from its burrow at night when there is no danger of it being

The Portuguese man o' war *(Physalia)* floats at the surface of the sea on its large air sac or pneumatophore, blown about by the wind and drifting in the surface currents.



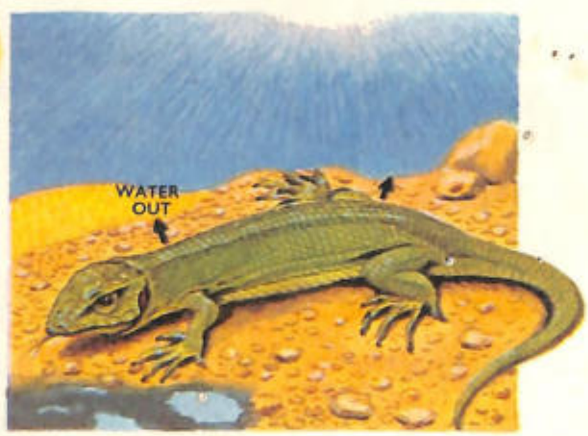
A selection of the many different kinds of invertebrate animals.

▲
The moray eel is a voracious marine creature that lives on other animals such as the octopus that it is shown preying on here. Eels are most unlike the other bony fishes, having long, serpent-like bodies. That of the moray eel may reach a length of ten feet. It is a giant amongst eels.

(left) Sponges are simple creatures that live in water. Some exist singly and others, such as the one in the illustration, live as colonies. Each sponge unit consists of a hollow vase-like sac with holes in its walls (see enlargement in the inset) and one or more large openings at the top. The inside of the vase has tiny collar cells each equipped with a long hair or flagellum. The rhythmic beating of these draws water in through the holes in the wall of the sponge, so carrying small particles of food and a current of oxygen. These are extracted and waste passes out of the vase in the water current through the large opening at the top.

The lizard faces a problem shared by all land animals, that of finding and conserving water. This is the principal reason why the land is such a difficult environment in which to live. The water that its body tends to lose to the relatively warm, dry air has to be replaced by water that it drinks or water in its food.

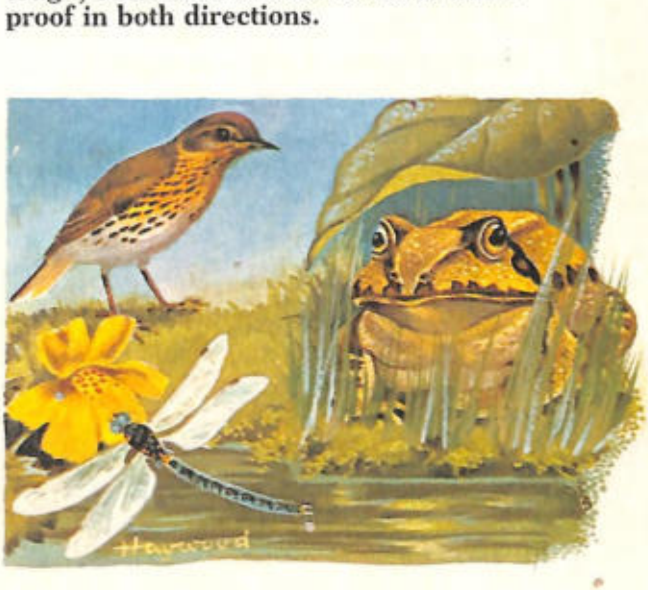
▼

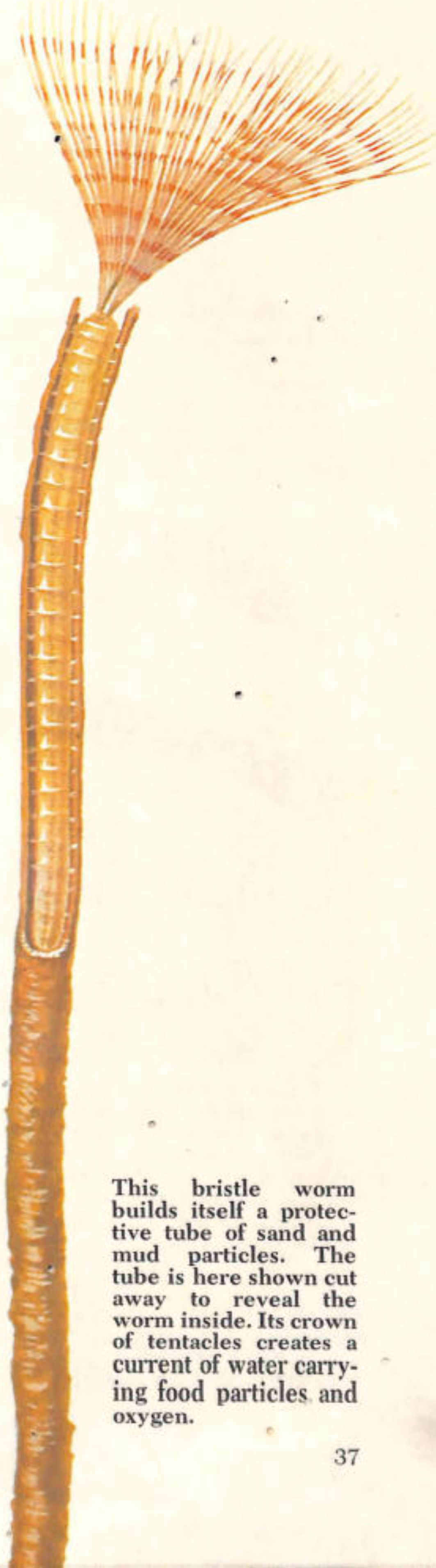


scorched by the burning rays of the sun. Similarly most desert animals hide in the shade during the daytime. Land dwelling animals obtain the water that they require in their food and by drinking.

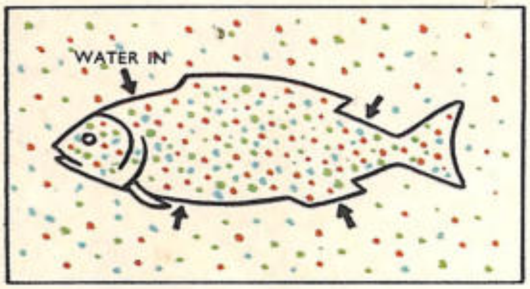
The problem concerning water is not the same with creatures that live in the sea and in freshwater lakes and rivers. There is more salt in the blood of a freshwater fish, for example, than there is in the water it lives in. There is a tendency for water to try to enter its tissues therefore. Freshwater fishes have a waterproof covering of scales and in many (e.g. eels) the skin produces large quantities of slime, restricting the entry of water into the body largely to the gills

The frog, bird and dragonfly share the problem facing the lizard, that of obtaining and conserving sufficient water. The bird has no sweat glands and a protective covering of feathers, which helps to restrict water loss; the frog lives in damp, shaded places, and the dragonfly saves water to a certain extent by having a tough, outer skin or cuticle that is waterproof in both directions.

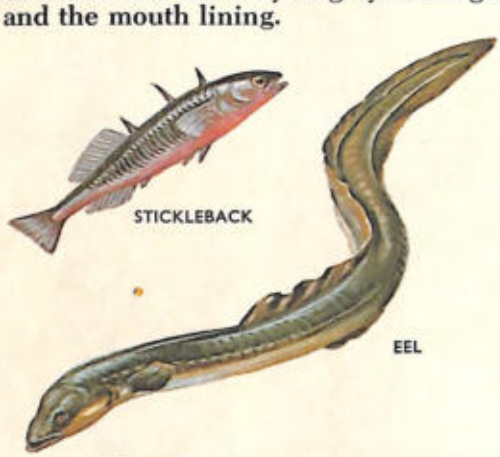


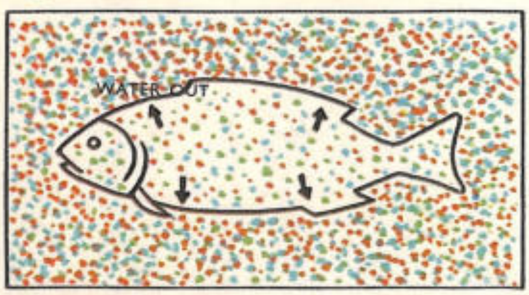


This bristle worm builds itself a protective tube of sand and mud particles. The tube is here shown cut away to reveal the worm inside. Its crown of tentacles creates a current of water carrying food particles and oxygen.



Freshwater fishes such as the eel and the stickleback have the same problem as freshwater invertebrates. They have a waterproof covering of scales and in many (e.g. eels) the skin produces large quantities of slime, restricting the entry of water into the body largely to the gills and the mouth lining.





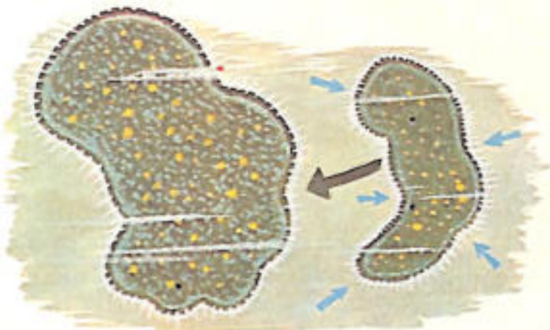
Salt-water fishes face the reverse problem to freshwater fishes since the blood contains less salt than the sea. They swallow large quantities of sea water to obtain water, but then have to remove the large quantities of salt that they have taken in through special salt-secreting cells in their gills.

and the mouth lining. A salt water fish on the other hand has less salt in its blood than the sea. The tendency will be for water to pass from it into the sea therefore. The fish overcomes this by swallowing large amounts of water and in order to keep the quantity of salt in its blood at the right level salt is removed through the gills.

Land dwelling animals may have a hard, waterproof outside (e.g. insects) or a dry protective scaly covering (e.g. reptiles). Birds have feathers which help to conserve heat as well, and their skin lacks sweat glands. Mammals have a covering of hair and this is also insulatory.

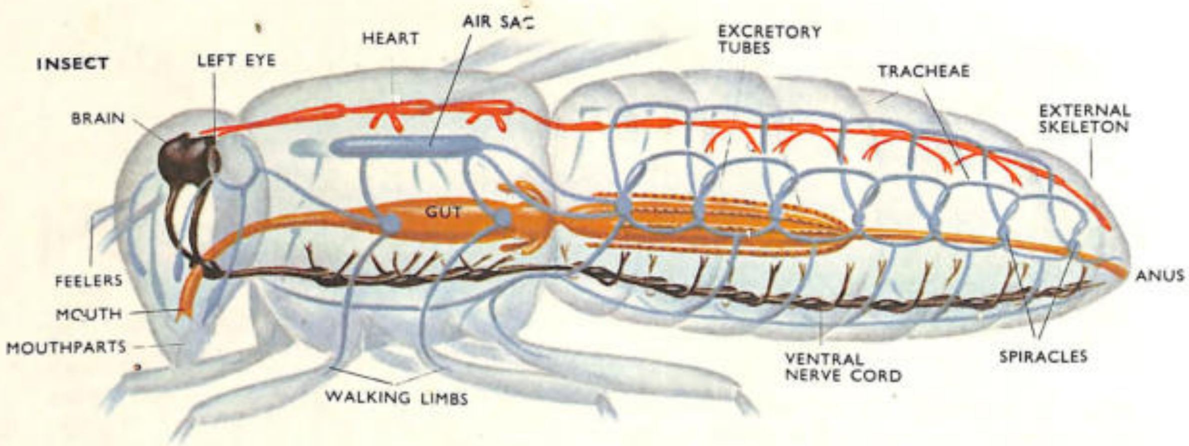
Many water creatures feed by creating a current of water which they draw into their bodies or towards their mouths. Any food carried in this current is extracted. Of course, just as on land, there are many predatory creatures which hunt their food. Similarly there are plant-eaters and there are flesh-eaters.

Besides using the water currents for feeding, many animals extract oxygen from the water too. Sponges, for example, have pores in the sides of their vase-like bodies in through which a current of water is sucked. They obtain both nutriment and oxygen in this way. Any creatures, such as tubeworms, have a third use for the water current. Besides extracting oxygen and food, they use some of the rejected particles for building the sandy tubes in which they live. Over their feathery tentacles are hundreds of minute hair-like structures called cilia. These wave to-and-fro in the water drawing a water current over the tentacles towards the mouth. Along the midrib of each tentacle is a groove, wide



Simple invertebrates living in fresh water have protoplasm containing more salts than the water in which they live so that water enters. They must remove surplus water to avoid swelling and eventually bursting. *Amoeba* has a special structure called a contractile vacuole which absorbs water from the surrounding protoplasm and periodically discharges water to the outside world.

(right above) Insects such as the cockroach have a hard, protective outer covering or cuticle that is waterproof. (centre) Birds have feathers which help to restrict water loss and also conserve heat, and their skin lacks sweat glands. (below) Snakes have a dry, protective scaly covering.

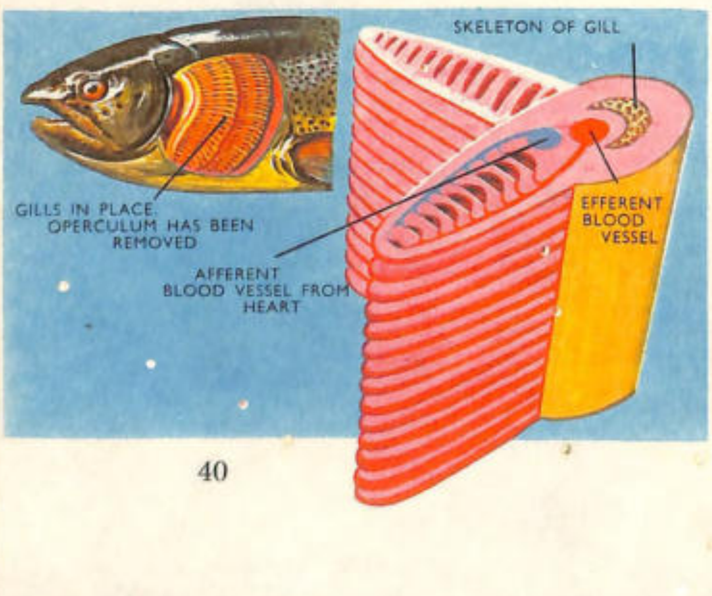


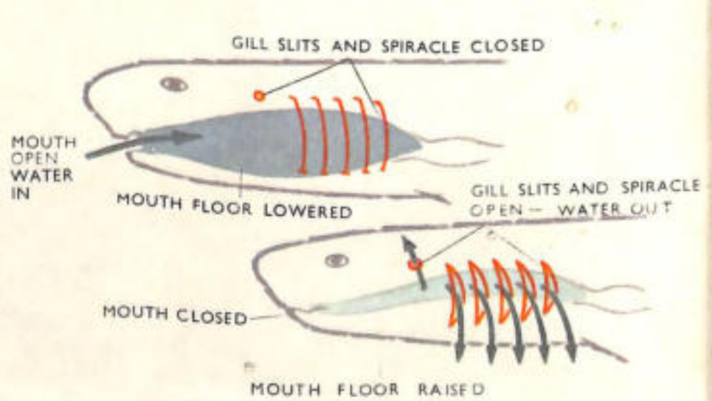
A transparent, diagrammatic view of a typical insect showing its structure. Insects have a system of hollow, internal breathing tubes or tracheae that form an intricate branching network in contact with the tissues. The most active flying insects have certain parts of the tracheae expanded as large air sacs. These form reservoirs for air and supply the large quantities of oxygen needed for flying.

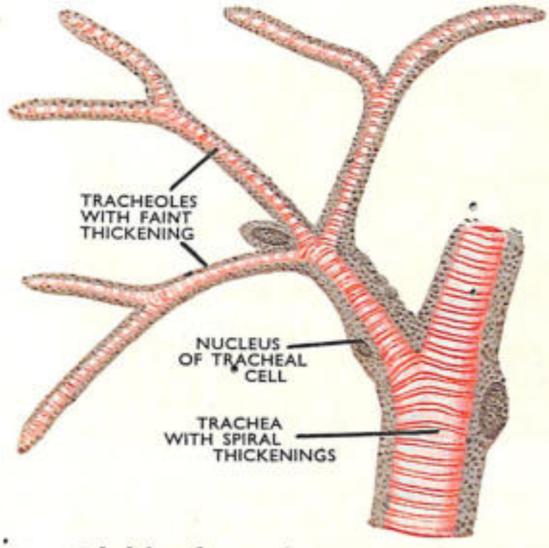
at the edge of the tentacle but narrower within. At its base around the mouth is a lip arrangement which accepts particles of a certain size for food and others for tube-building. The remainder of the particles are rejected and fall off the lip.

Most aquatic animals extract oxygen from the water. The structures most commonly found for this purpose are gills. A fish draws water in through its mouth and out over the gill slits. As the water passes over the gill tissues, which have a very

(left) The gills of a bony fish exposed by removing the gill cover or operculum and (inset, highly enlarged) several gill filaments showing the rich blood supply. Oxygen is carried by the bloodstream away from the gills to the tissues. (right) Diagrams showing the mechanism by which a flow of water is passed over the gills in a shark-like fish. First, with the gill slits closed, the mouth opens to admit water. The tongue and floor of the mouth are lowered to increase the volume that can be taken in and also to 'prime' the pump that forces water out through the gill slits when these are opened and the mouth is closed. The water is forced out by the floor of the mouth being raised.



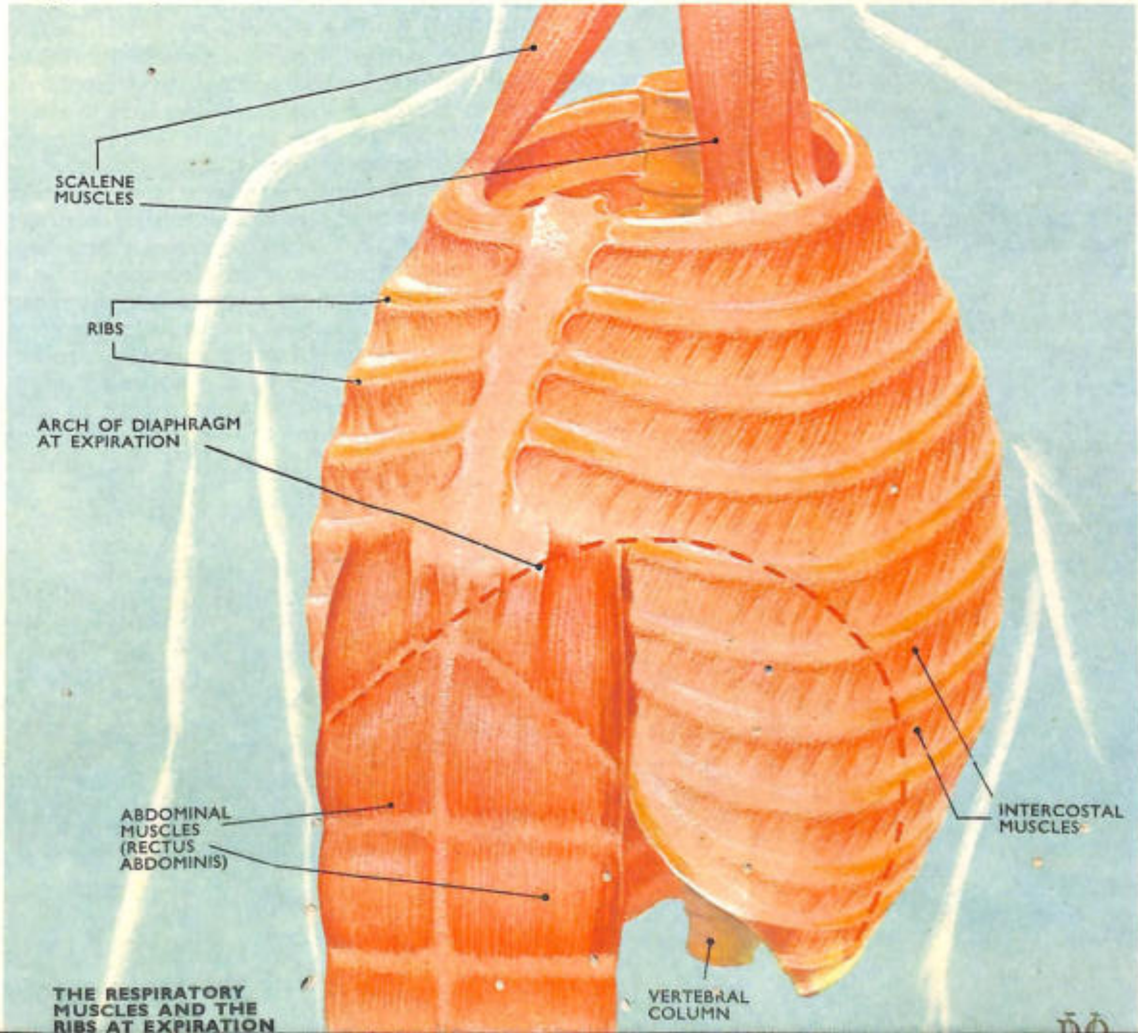


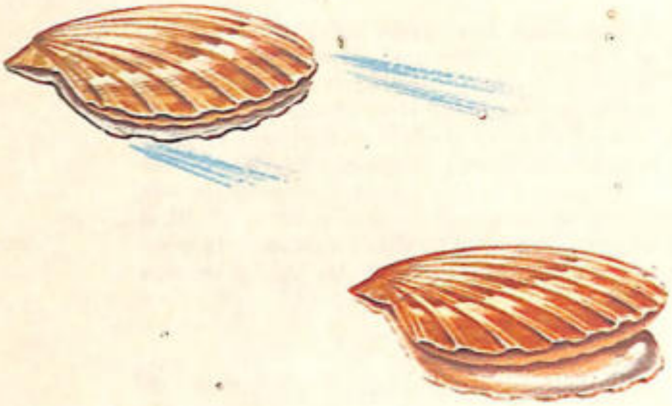


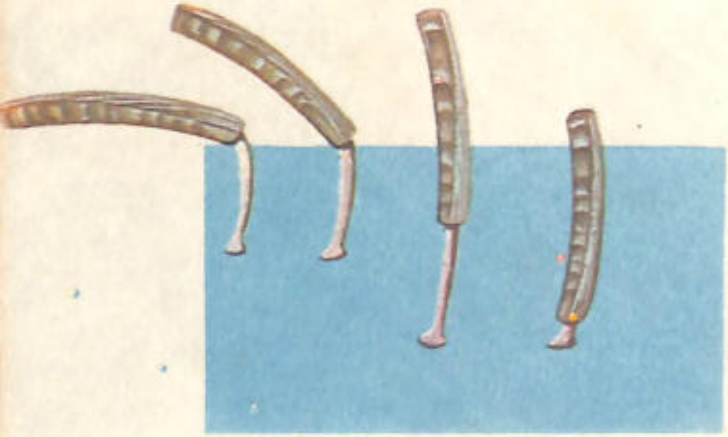
The hollow breathing tubes or tracheae of insects are strengthened by thickened regions of the walls which give the tubes the appearance of the windpipe in Man. The diagram shows a trachea (highly magnified) branching into very fine tubes or tracheoles. The finest tracheoles are in direct contact with the tissues, so that oxygen has only a short distance to pass from the tubes to the cells of the tissues themselves.

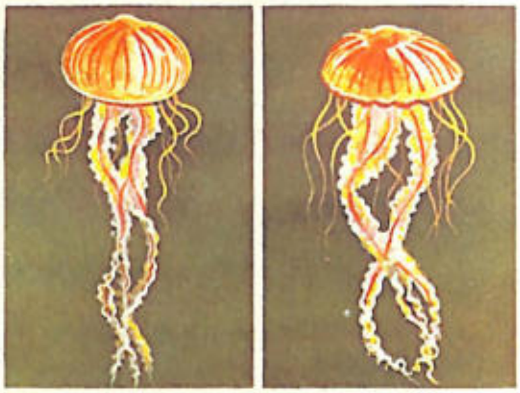
rich blood supply, oxygen is extracted from the water whilst carbon dioxide waste produced by the chemical activities of the tissues, is washed away in the stream leaving the gills. A few aquatic creatures breathe air in the same way that land-dwelling animals do. Such are whales, dolphins and porpoises which have to come to the surface to breathe, when the

The principal breathing muscles in the human body, shown in their respective positions at expiration. At inspiration the diaphragm contracts and so becomes flattened and lowered. The ribs are raised by the action of the intercostal muscles which results in the volume of the chest cavity being enlarged. The pressure acting on the lungs is reduced so they expand and air is forced into them by the pressure of the atmosphere. The scalene muscles and the rectus abdominis hold the rib cage at the top and bottom respectively.







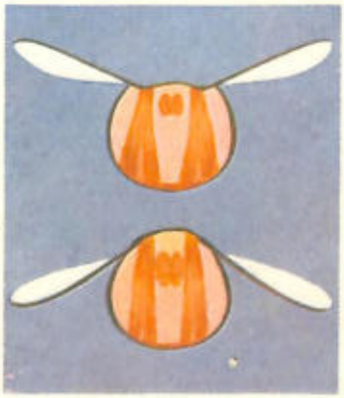


Creatures living in water show many different methods of moving through their surroundings. The jellyfish, shown above, fills its bell with water, the bell contracts forcing water out round the edge and the animal is propelled through the water. The scallop (top left) too has a jet-propelled way of getting about. It claps the two halves of its shell together violently shooting out a jet on each side. Starfishes have the undersides of their arms covered in tiny water-filled projections called tube feet. These are worked to and fro by muscles and each has a sucker at its tip so that it can grip and pull on the surface over which the starfish is moving. The tube feet act as tiny levers and the combined levering action of the numerous tube feet is sufficient to propel the starfish slowly along. Below the starfish is a cross-section of an arthropod's body to show the general arrangement of the muscles that operate the limbs in walking and running. (bottom left) Diagrams showing how a razor shell uses its foot to burrow into sand. This it is able to do faster than a man can dig down after it with a spade. The cuttlefish is a streamlined fast-moving mollusc. Contraction of its mantle causes a jet of water to shoot out of the funnel so propelling the animal along.

The water boatman has flattened hind legs fringed with hairs, so that a large surface area is presented to the water with each rowing motion. The pond skater (above) moves about on the surface of the water, supported on the surface film.

familiar spouting may be seen. Many aquatic insects breathe air, too. Some water beetles and bugs carry their own supply of air down with them in the form of an air bubble. Others stick

Diagrammatic sections through an insect's middle showing how the muscles operate to move the wings up and down during flight. When the wings are raised the vertical muscles contract and the lengthwise muscles expand (become smaller in cross-section). When the wings are lowered the lengthwise muscles contract and the vertical muscles relax.



up special tubes through the water surface to obtain air, for example, the mosquito larvae.

Animals on land have a variety of devices for obtaining air. Insects, for example, have a branching system of tubes within their bodies, called tracheae (track-ee-i). These open to the outside by way of openings (spiracles) along the sides of their

Buzzards, hawks and vultures are able to soar slowly upwards by spiralling round in hot up-rising air currents (thermals).

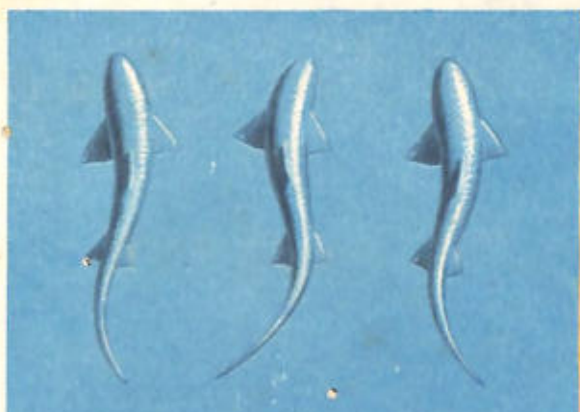
A view of a gull in flight showing how the feathers of the wing overlap to present a continuous surface to the air. (inset) A series of drawings showing the successive positions of the wings of a pigeon as they make one complete downward and upward movement.

bodies. Animals with backbones (vertebrates) that live on land have lungs. Air is drawn into these by means of muscle movements. In some, such as frogs, the moist skin is also very important in breathing.

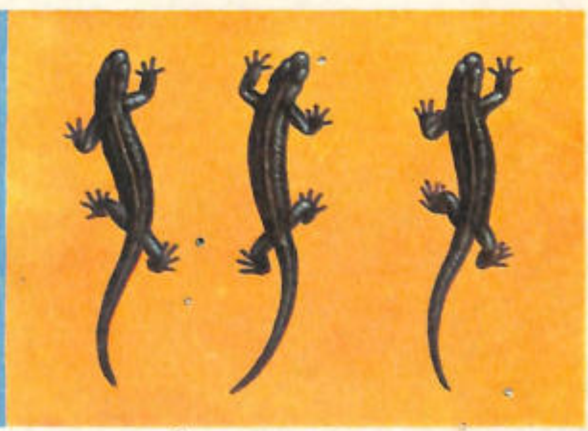
Movement in water and on land are very different problems. Firstly an animal is buoyant in water and so its weight is supported by the water. Consequently it does not need a strong skeleton. The land does not provide support in this way and most land-dwelling animals have a strong skeleton, either an internal one such as the bony skeleton of a human being or an external one such as the horny shell of an insect. The muscles concerned with movement are attached to the outside of an inner skeleton and to the inside of an outer skeleton. Some terrestrial animals employ the same wriggling movements as do fishes in water (salamanders for example). Snakes too bend their bodies in a series of waves and push on the ground just as a fish pushes its body against the water. But the majority of land-dwelling creatures raise their bodies clear off the ground on limbs when they walk or run.

A hare has very long hind legs which work together to give it the tremendous forward drive that it makes use of in escaping enemies such as the fox.

Some creatures have evolved wings and are able to move in air. Such are many insects, birds and bats.



The dogfish bends its body so that a moving wave passes along it from front to rear. The bend in the body thrusts against the water, pushing the fish forwards.



In a salamander the body bends in a similar way to that of the dogfish with the limbs used as levers to hold the body off the ground.

CHAPTER 5

The pattern of life

ALTHOUGH there are so many different kinds of living things, each having its own position in its surroundings and living in its own particular way; there is a basic plan or pattern to their activities. Each day sees similar life and death struggles between animals and plants and between one animal and another. This has gone on for millions of years and will continue so long as there is life on earth.

Plants must have evolved before animals because those with chlorophyll release oxygen into the atmosphere during their food-making processes. The animals need this in order to survive. Animals cannot make their own food. They must obtain their food ready-made, and break it down by their digestive processes so that the small molecules can be incorporated into their own systems. This is the basic difference between animals and plants, and consequently all animals, whether they eat plants or other animals, rely on plants for their food. For even a meat-eater eats an animal that itself must have consumed plant food.

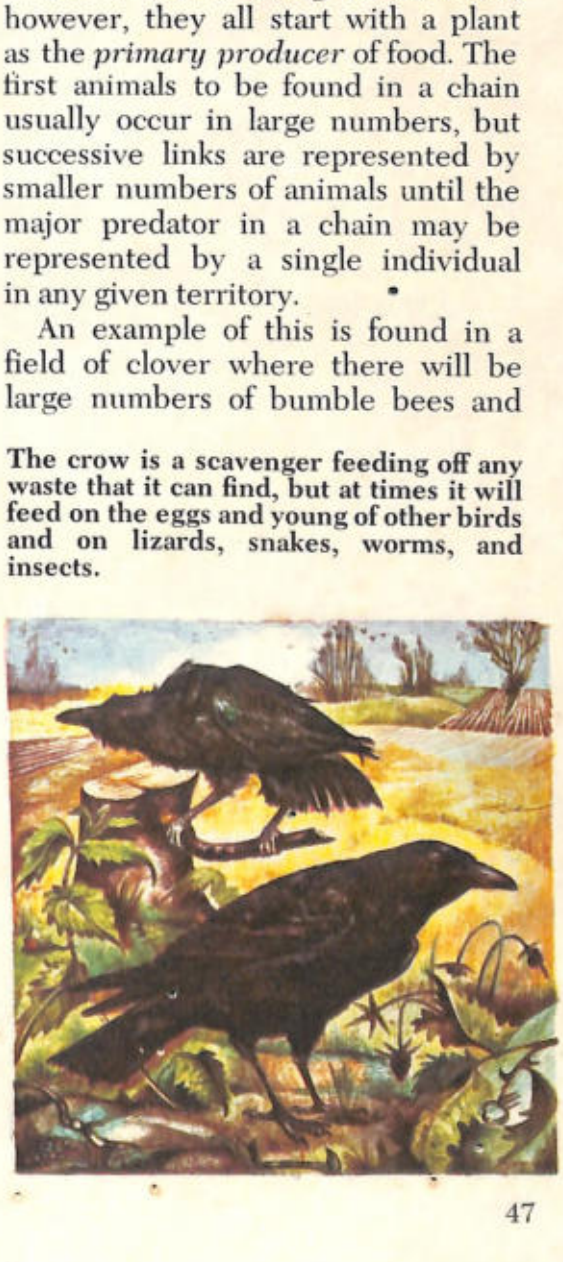
The relationship between animals and plants may be a simple one, such as when a cow eats grass. In this instance the animal is consuming plant food directly. A slightly more complicated relationship is that of an antelope eating grass and itself being preyed on by one of the large flesh-eating cats such as a lion. These relationships are known as *food chains,* and they must be made up of many links, many more than in the two examples above.

On the sea floor there are daily life and death struggles similar to those on land as each creature ekes out its existence.

All have one thing in common, however, they all start with a plant as the *primary producer* of food. The first animals to be found in a chain usually occur in large numbers, but successive links are represented by smaller numbers of animals until the major predator in a chain may be represented by a single individual in any given territory.

An example of this is found in a field of clover where there will be large numbers of bumble bees and

The crow is a scavenger feeding off any waste that it can find, but at times it will feed on the eggs and young of other birds and on lizards, snakes, worms, and insects.



A typical food chain. Aphids feed on a variety of plants, sucking the sap with their piercing and sucking mouthparts. They may be preyed on by spiders who are consumed by small warbler-like birds. These and small mammals are consumed by birds of prey, the young of which fall victim to predatory mammals such as stoats and weasels.

their underground nests. Field mice, present in small numbers, feed on the young bees in the nest and are in turn hunted by hawks. There will probably be only one hawk family or one hawk in the immediate area. The distribution of the hawks depends upon the available food. An area containing five hundred mice obviously cannot support many hawks, as the food supply of the latter would soon be exhausted.

Similar chains are found in the sea. The small planktonic plants—the primary producers—are eaten by planktonic animals which in turn form the food of the shoaling fishes, such as herrings. The shoals contain large numbers of fish and are preyed upon by larger fish such as the cod which is not so common and does not swim in shoals. Creatures such as squids and seals consume cod, and squid are often eaten by sperm whales.

Man can be placed at the head of a great number of chains because he uses a wide variety of natural products for food. He may interfere in the last food chain mentioned, catching both cod and herrings, and, in smaller numbers, seals and sperm whales. Man is, of course, far more common than many of the animals he uses for food, but this is a specialised case and the general rule of decreasing numbers still holds good in other cases.

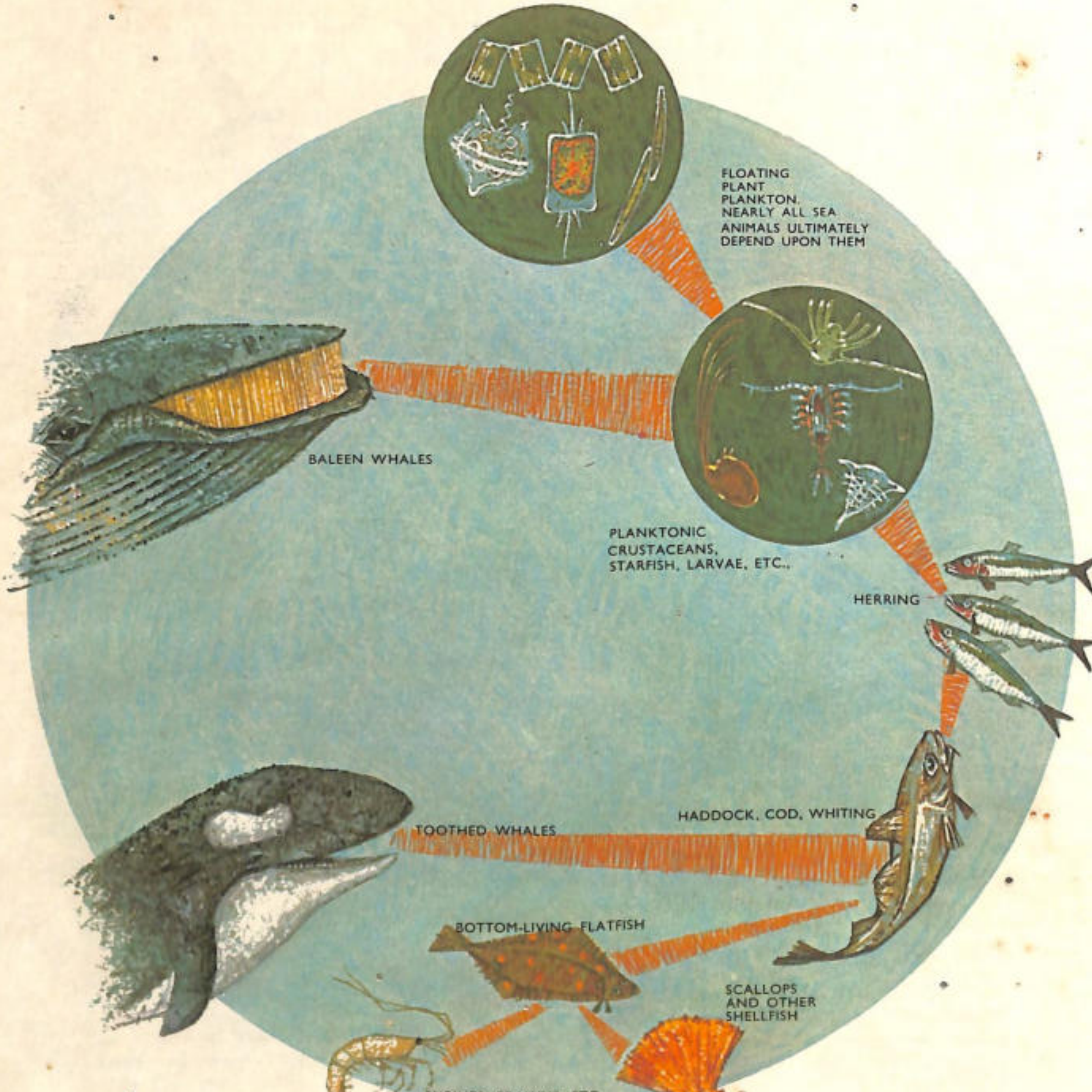
Parasites—animals that feed in or off others causing them harm—must be included in food chains to give a complete picture. The final stage in this case consists of very large numbers of small animals feeding on a

A diagram illustrating a few of the interrelationships between plants and animals of land and fresh water. Obviously many more examples could be included in a more comprehensive chain or series of chains. Man for example takes far more than just milk and meat from his surroundings.

single very large one. A fish may have hundreds of parasitic roundworms inside it. A man ill with malaria has many thousands of protozoan parasites in his blood. Where a parasite has more than one host, cross-links are produced between food chains.

The food chains must not be thought

A food chain in the sea. The small floating plants in the sunlit surface waters of the ocean are the starting point for nearly all the food chains in the sea. Directly or indirectly these plants support most marine animals.



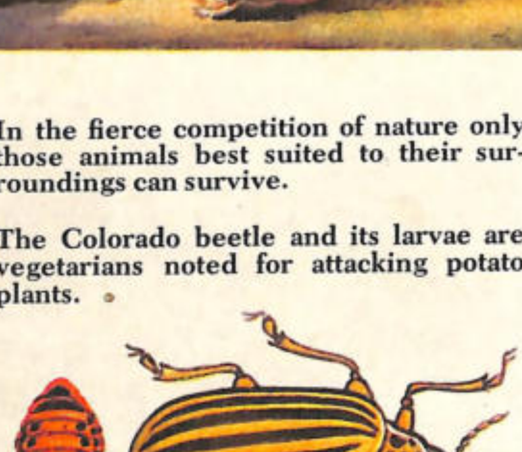
of as simple, straightforward relationships involving only a few animals, however. All the individual food chains found in a particular environment are linked together in some way so that the structure of the plant and animal population remains stable in any area. To take the clover field example once more, mice are preyed upon by cats as well as hawks, and also by owls. Cats occur at the head of the chain leading from dead clover plants via worms and birds, and thus link two chains starting with a clover plant. In theory the number of cats influence the yield of clover seeds via the activities of mice and bees, but so many factors are acting in nature that the effect would probably be balanced out. It is true, however, that severe reduction in the numbers of a common animal will change a lot of things in an environment. Myxomatosis, which killed large numbers of rabbits in Britain a few years ago, deprived the foxes of much of their natural food. They began to catch birds much more frequently as many poultry keepers discovered. The fact that rabbits no longer grazed on open hillsides also meant that bushes were able to sprout and so the landscape started to change, though slowly.

In the sea, the chains are linked together in much the same way. Individual animals may by-pass some of the steps. For example,

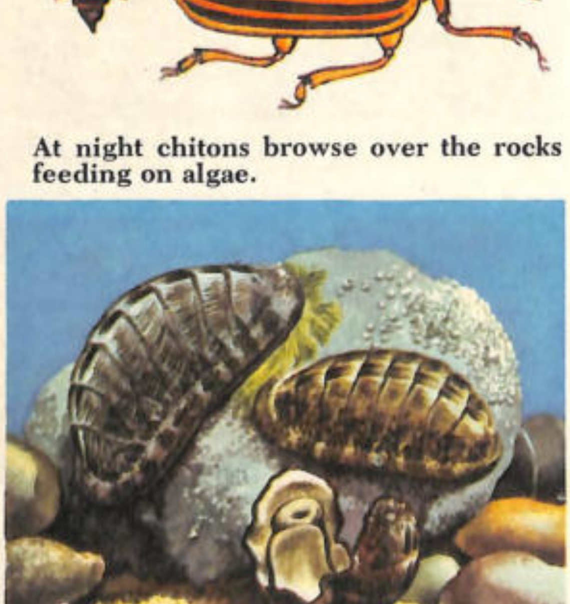
(above right) The lion and the tiger are carnivores preying on the grass-eating hoofed animals such as antelopes.
(centre) Rotifers or wheel animalcules, shown here highly magnified, are filter feeders on tiny particles of food.
(bottom right) The lancelet is abundant around the coasts of Britain. It too feeds on tiny particles of food that are drawn towards it by means of cilia.

In the fierce competition of nature only those animals best suited to their surroundings can survive.

The Colorado beetle and its larvae are vegetarians noted for attacking potato plants.



At night chitons browse over the rocks feeding on algae.



the large whalebone whales feed directly upon the minute planktonic organisms. The dying planktonic organisms sink to the sea bed where they are eaten by molluscs, annelid worms and other creatures. These in turn are eaten by starfish, cuttlefish and bottom-living fishes, such as cod and plaice. Large squids eat all types of animals on the sea bed and they themselves form the main diet of elephant seals and the large, toothed whales such as sperm whales.

Dead animals, including the large carnivores which have no natural predators, but which die from disease or old age, are consumed to some extent by scavenging animals such as burying beetles, vultures and hyaenas. A proportion of the organic material, however, will be broken down by bacteria and provide simple compounds which plants will again build up into organic food materials. Similarly in the sea dead animals are decomposed and the dissolved salts are returned by currents to the surface layers where they are taken in by the planktonic plants.

Strictly speaking a food chain never

ends because the largest of carnivores must die and their remains are returned to the general circulation of materials in nature.

The nitrogen cycle

Both plants and animals need nitrogen in order to build up their tissues. Plants obtain their nitrogen from certain nitrogen compounds in the soil and build it up into complicated chemicals called proteins. When the plants die the nitrogen will be returned to the soil where it is acted upon by the countless millions of tiny inhabitants called bacteria, and released in a form which other living plants can absorb. Or alternatively the plant may be eaten by an animal and the plant protein is broken down by the animal's digestive system and in the animal's tissues built up into animal protein. The droppings of an animal contain small amounts of nitrogen or it may die, when the remains are acted upon by small animals and bacteria and broken down into simple nitrogen compounds which the plants can absorb. There are many and varied paths which the nitrogen may take. This circulation of nitrogen between

(above right) Bumble bees feed off flowers.
(centre) Most opossums are voracious carnivores feeding on small mammals and birds. The species shown here has a prehensile tail suiting it to life in the trees. The Virginian opossum is omnivorous, feeding on flesh and fruit, crayfish and a number of other things.
(bottom right) These are insectivorous bats. Besides using their echo-location system for navigation – sending out high-pitched squeaks and picking up the echoes from objects in their path – they are also able to detect the echoes from insects and the system is thus of use for feeding in twilight conditions.

Lichens form encrusting structures on rocks and trees; others are feathery. They are really two plants in one, an alga and a fungus. The alga has chlorophyll and is able to make food from simple chemicals using the energy of sunlight and the fungus receives food from the alga. Reindeer moss is the special food of the reindeer.

living things, the atmosphere and the soil is called the *nitrogen cycle*.

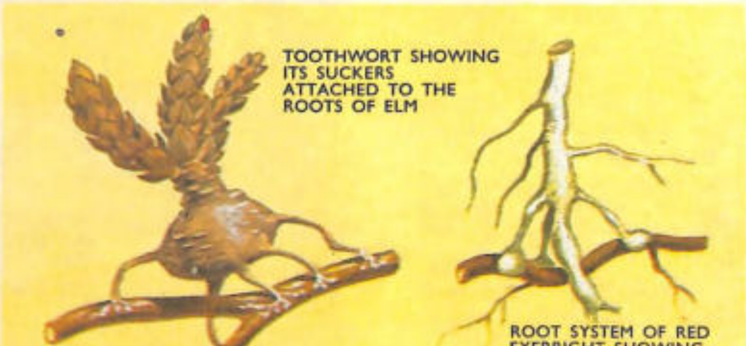
It is important that plants have enough nitrogen in their diets, and so there must be a constant supply of its compounds in the soil. As soon as these nitrogen compounds are removed more must be put back to take their place or else the plant life will suffer. One way in which they can be returned to the soil is from the decaying remains of plants and animals.

About four-fifths of the air is nitrogen. This represents an enormous supply of the element. If we could breathe in nitrogen and convert it into protein the problem would be a simple one. But this does not happen, for the nitrogen breathed in is breathed out again unchanged. This supply is not available to plants either except a few bacteria and certain algae.

A plant growing in soil that contains no nitrogen will eventually wither and die, even though its leaves are surrounded by the nitrogen in the air. Pure nitrogen, the element itself, is very unreactive. Plants need certain *compounds* of nitrogen such as nitrates.

There are, however, certain bacteria living in the soil that can utilise atmospheric nitrogen. Because they can take in nitrogen from the

Many species of plants are parasitic on others. Toothwort is a plant lacking chlorophyll that is especially found on the roots of elm; red eyebright is another colourless parasite, living on the roots of grasses.

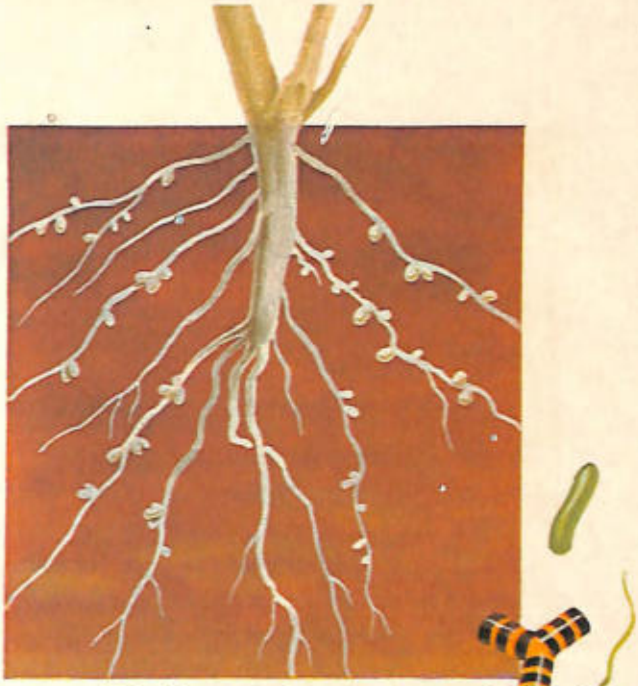


air and convert it into nitrates they are called nitrogen-fixing bacteria. Some live in swellings called nodules on the roots of legumes such as clover and peas. The legume is able to use some of the nitrate produced and the excess goes to enrich the soil. The planting of a field of clover and the end-of-season ploughing-in is often used by farmers to enrich the soil.

Within the soil are a host of other bacteria, some building up nitrogen compounds and others breaking them down, but all helping to keep a balance of nitrogen in the soil for plant use. As you can see from the illustrations food chains are really a part of the nitrogen cycle.

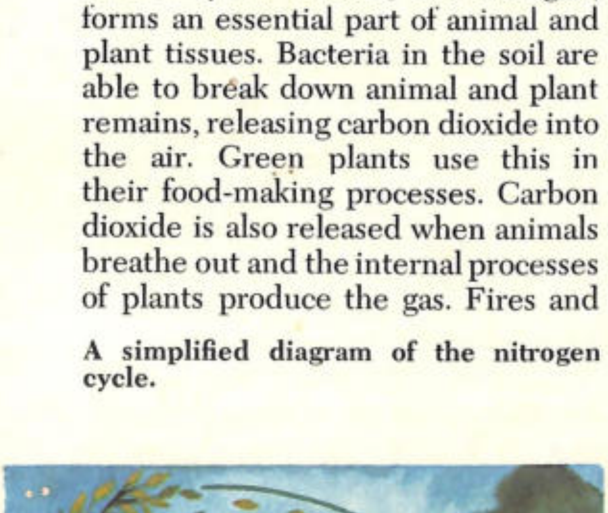
The carbon cycle

Another well-known cycle is the carbon cycle. Carbon, like nitrogen, forms an essential part of animal and plant tissues. Bacteria in the soil are able to break down animal and plant remains, releasing carbon dioxide into the air. Green plants use this in their food-making processes. Carbon dioxide is also released when animals breathe out and the internal processes of plants produce the gas. Fires and

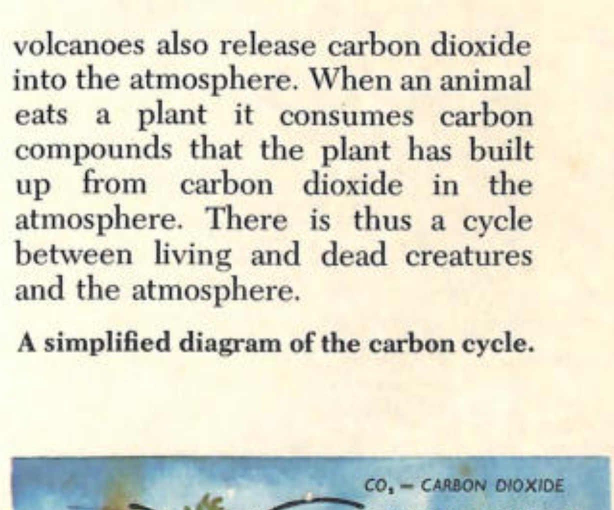


Root nodule bacteria live in tiny swellings called nodules on the roots of legumes (e.g. clover, pea, vetch). They fix atmospheric nitrogen, building up inorganic nitrogen-containing molecules, which the legume can obtain from them through its vascular tissues. The bacteria obtain sugars in return.

volcanoes also release carbon dioxide into the atmosphere. When an animal eats a plant it consumes carbon compounds that the plant has built up from carbon dioxide in the atmosphere. There is thus a cycle between living and dead creatures and the atmosphere.



A simplified diagram of the nitrogen cycle.

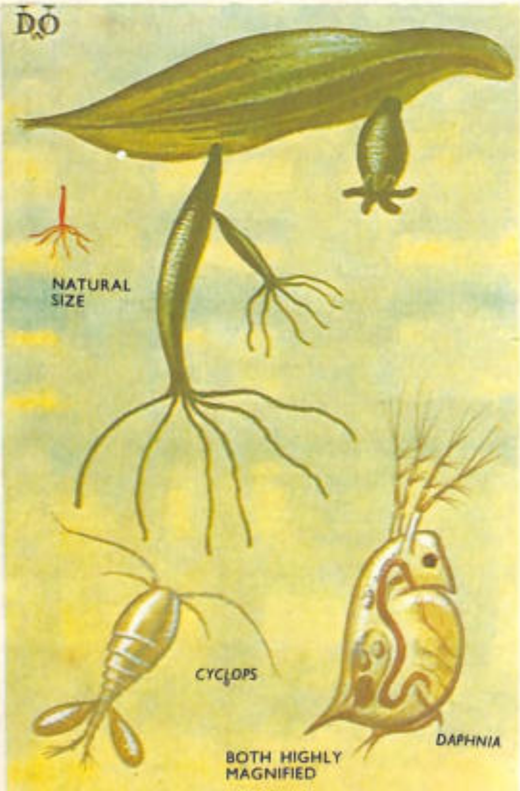


A simplified diagram of the carbon cycle.

CHAPTER 6

Animal adaptations

THERE are at least one and a half million different kinds of animals. It is hardly surprising therefore that there are many patterns of equipment for living. Each species has its own characteristic structures suiting it for its particular way of life. Some are concerned with the catching of food, others with defence, some with movement, and some with attraction of the opposite sex. The list is almost inexhaustible.



(at top) *Hydra* extended and contracted. Muscles in the body wall produce the variation in size. Below the hydra are two small crustaceans on which it feeds, both highly magnified.

Hydra is a tiny creature that lives in ponds and other bodies of fresh-water. It is not too small to be seen with the naked eye but it is very difficult to see in its natural home. It consists of a long, hollow sac with one opening, the mouth, in through which food is passed. Surrounding the mouth is a ring of tentacles, like long waving arms. These carry tiny structures – stinging cells – which are the hydra's armoury. Each is a sac within which is a coiled thread. When the stinging cell is stimulated, as by a passing water flea, it is discharged. The thread shoots out, piercing the water flea if it is within range. Several stinging cells are usually triggered off at the same time and the trapped water flea is paralysed by a poison almost as powerful as cobra venom.

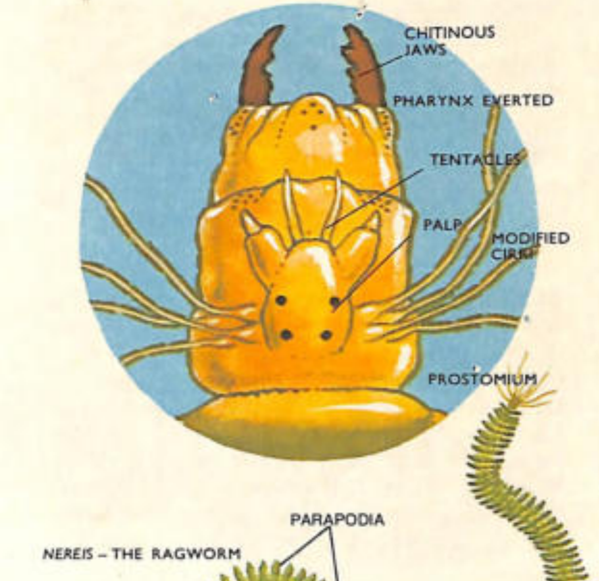
Not all the 'stinging cells' penetrate the prey. Some are sticky and merely serve to hold the prey so preventing its escape. Whilst it is held and paralysed the water flea is surrounded by the tentacles which then draw it towards the mouth of the hydra for consumption. Many other relatives of *Hydra*, such as sea anemones, have stinging cells and catch their prey in a similar way. Anemones are of course much more powerful and can trap quite large fishes.

The sea gooseberries used at one time to be placed in the same group as *Hydra*, but they lack stinging cells. The majority have long tentacles which are armed with sticky lassoes, special structures for catching prey. The tip of each lasso cell is sticky and the prey becomes entangled in it.

The ringed or annelid worms exhibit a remarkable array of adaptations. A common bristle worm is the ragworm, *Nereis*. Its bristles arise from leaf-like structures called parapodia of which there is a pair to each segment, one on each side of the body. *Nereis* spends most of its time in shallow burrows, the sharp bristles which at other times probably protect it serving to hold it in the burrow. Gentle waving movements of its body cause water to move in and out carrying oxygen and possible indications of food in the vicinity. When small animals do pass the burrow the first part of the gut—the pharynx—is turned inside out so that it extends from the burrow. On the end are two pairs of horny black jaws for gripping the prey. Apart from spending time in its burrow, *Nereis* may also wander along the shore using its rows of paddles for swimming or merely undulating its body.

Tomopteris is a remarkable worm whose parapodia are enormous lobes projecting from the sides of its body. It lives in the open sea and swims very well using its huge paddles.

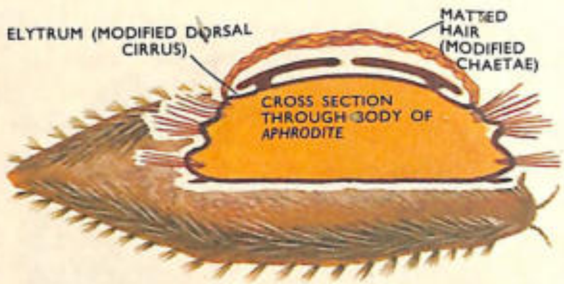
Aphrodite, the sea mouse, is an extraordinary creature covered in scales and resembling the chiton molluscs. Bristle worms have in addition to the parapodia certain flaps of tissue called cirri. In *Aphrodite* the uppermost ones curve upwards and backwards on either side of the body and overlap on the top



Nereis*, the ragworm. The 'rags' are the leaflike parapodia on either side of the body. (inset, above) An enlarged view of the head showing the sensory equipment – tentacles and cirri – and the reversible jawed pharynx for catching food.

A terebellid worm. The colourful tentacles on the head are numerous and modified for capturing small food particles. The tube is normally buried in the sand.

surface. Its scales are covered by a dense mat of hair—hence its name of sea mouse—beneath which is a hollow space. Lying in its muddy



Aphrodite, the sea mouse, is a scale worm. The uppermost scales curve upwards and backwards on either side of the body and overlap on the top surface. Its scales are covered in a dense mat of hair; hence its name of sea mouse. Superimposed on it is a cross-section of its body showing the hollow cavity under the hairs through which an oxygen-carrying current of water is pumped.

Tomopteris, a free-swimming worm that lives in the open sea. It has very large parapodia which it uses for swimming.

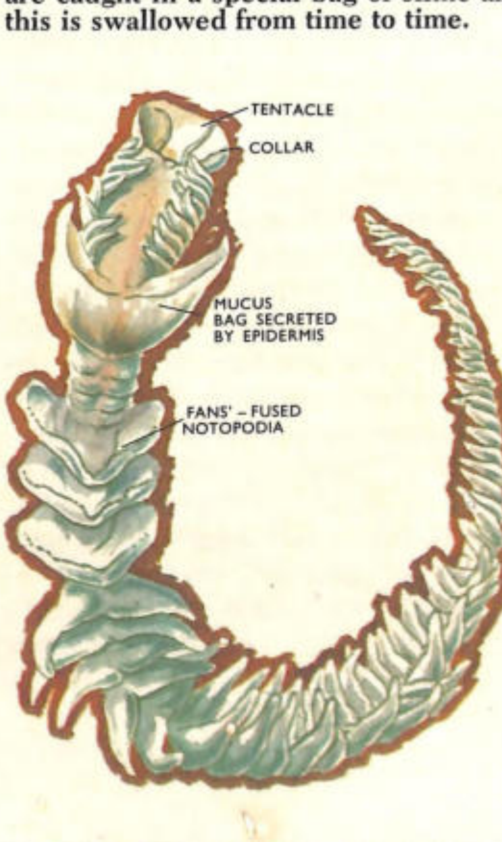
burrow in offshore waters, water is continually pumped through this space and the scales probably serve to extract oxygen from the water.

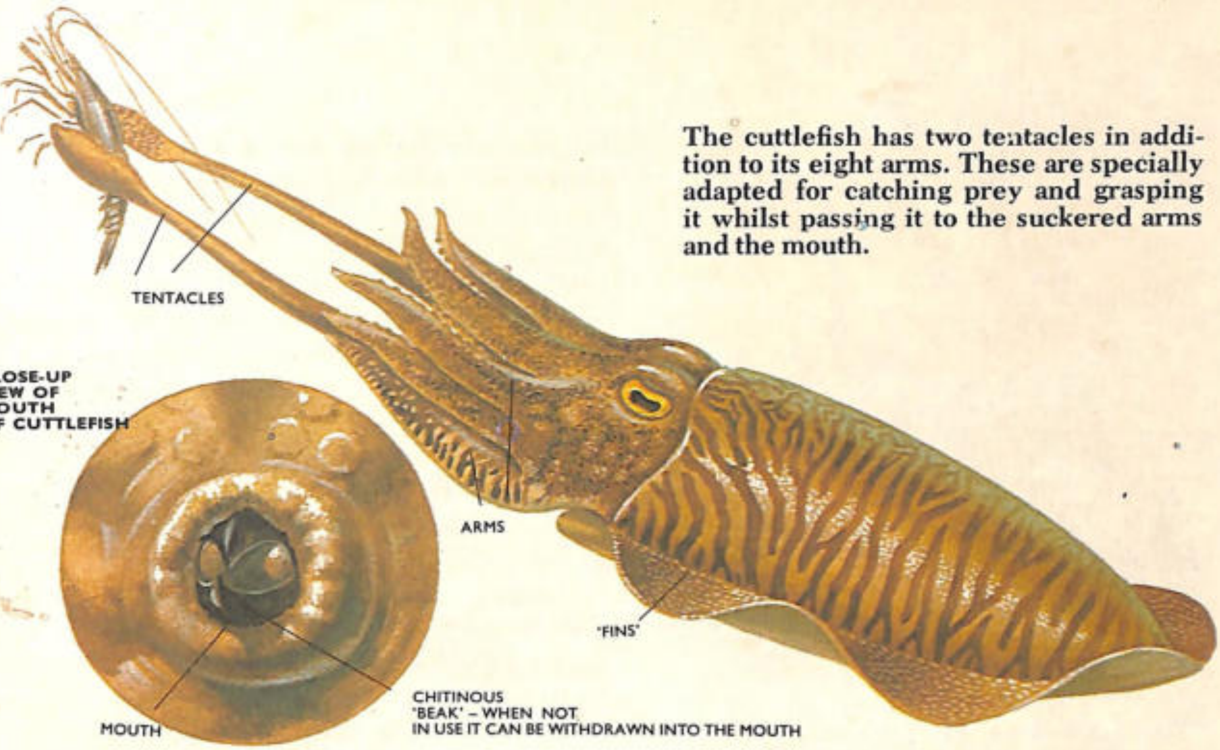
Distinct from the wanderers and shallow burrowers are the tube-making bristle worms. They actually construct their own homes. Usually they bear numerous long tentacles on their heads. These are primarily food-collecting structures but they also serve as sense organs, being very sensitive to disturbances in the surrounding water. Tube-living worms are filter-feeders, that is, they live by separating or filtering off food particles from mud and other material in their surroundings.

The tentacles projecting from their heads each has a groove down its inner surface which bears tiny hair-like threads called cilia. The cilia beat by waving to and fro and so draw a current of water carrying food and other particles towards the mouth of the worm. In a worm called *Sabella* there is an extraordinary mechanism for sorting food from other matter. At the bottom of the tentacle the groove deepens and this forms the sorting mechanism. Small particles drop right down into the groove, medium-sized particles are carried in the upper part of the groove whilst the largest particles are too large to enter the groove. The latter are carried away by special bands of cilia, the medium-sized particles are used to build the tube, and the smallest particles are led towards the mouth for consumption.

The most modified of all tube-building worms is *Chaetopterus*. It

Chaetopterus is perhaps the most extraordinary polychaete. It lives within the sand in a 'U'-shaped parchment-like tube. Some of the parapodia are large and fan-shaped and are used to circulate water through the tube. Food particles are caught in a special bag of slime and this is swallowed from time to time.





The cuttlefish has two tentacles in addition to its eight arms. These are specially adapted for catching prey and grasping it whilst passing it to the suckered arms and the mouth.

lives within the sand in a 'U'-shaped parchment tube. Some of its parapodia are large and fan-shaped. Their waving movements circulate water through the tube for breathing purposes and also for feeding. Skin cells near the front end of the worm produce a bag of slime in which food particles are trapped, and this bag of food is swallowed from time to time.

Tales of sea monsters, furious creatures with many arms, huge heads and hideous eyes are recorded in many past writings. Some of the tales are completely fanciful; others, though undoubtedly exaggerated, nevertheless seem to be based on actual encounters. From their descriptions the monsters seem to have been real animals, members of a group today called the cephalopods.

All live in the sea. The cuttlefish in addition to its eight arms has two tentacles which can withdraw into pockets beside its eyes. Suckers cover the inside surfaces of the arms

Parts of the arms of a cuttlefish, squid and octopus showing the differences between the suckers and their arrangement.

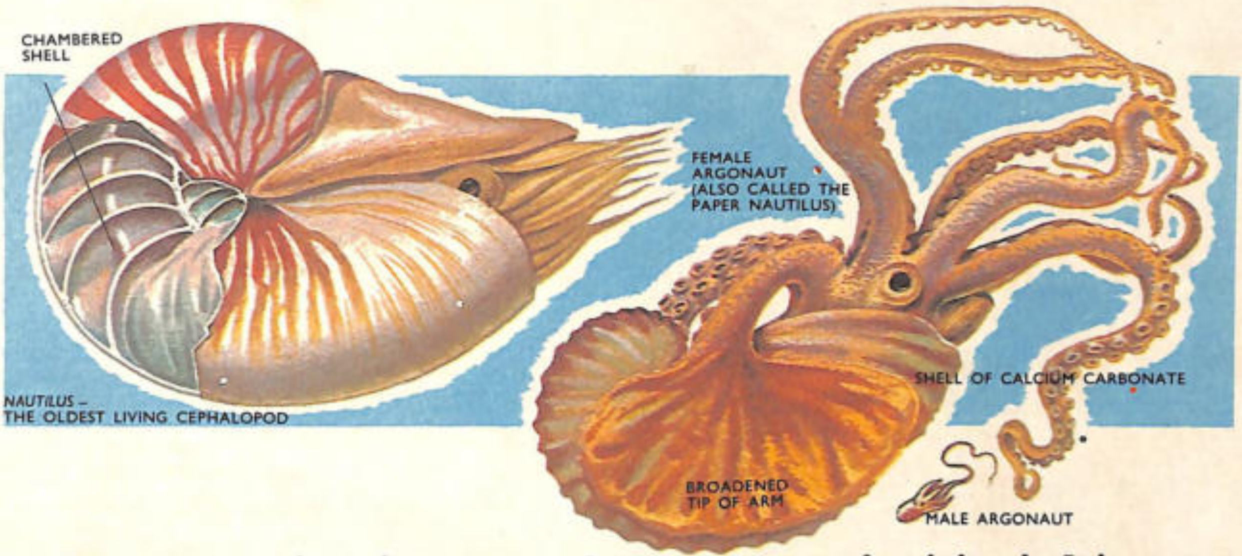
The cuttlebone of the cuttlefish is a beautifully designed structure, not merely a support but also a delicate buoyancy mechanism.

and the club-shaped ends of the tentacles. These suckers, unlike those of the octopus, have teeth on the outer rims. They are cup-shaped structures which adhere to prey and other objects. The two tentacles are specially adapted for snatching prey and grasping it whilst passing it to the suckered arms and the mouth. Cuttlefish live mostly in shallow water among rocks and on sand. They feed on crabs, shrimps, prawns and small fish.

Although not the kind of creature that most would choose for a pet, many cephalopods are among the most colourful of animals. The deep-sea types are especially pretty, having light-producing organs or photophores. These may be of use in enabling one cephalopod to distinguish another hunter from a hunted creature, or it may enable male to recognise female in the dim unlit waters.

Octopuses, squids and cuttlefish are also able to change colour. The power of colour change of the octopus surpasses that of the chameleon. The ability enables it to remain well camouflaged when lurking for prey or when actively pursuing it. Bright colours are also displayed when escaping enemies, perhaps as a device for confusing the pursuers. Another ability is the production of ink in an ink sac. Ink is discharged when

Many deep sea cephalopods are equipped with light-producing organs. The exact significance of these structures is not fully understood but they may enable the sexes to recognise each other in the dark, unlit deeps.



(left) *Nautilus*, only modern survivor of an ancient group of cephalopods. It has a pearly shell made up of several chambers. The animal inhabits the largest one and the remainder are filled with gas and act as buoyancy chambers. (right) *Argonauta*, strange octopuses that swim in warm, surface waters. The 'shell' is not a true shell and is used by the female to shelter the developing eggs.

the animal is in danger. In the cuttlefish this undoubtedly acts rather like a smokescreen laid by a destroyer for instance, but in other cephalopods the ink is mixed with slime and forms a shape which is not large enough to conceal the animal. Most likely it acts as a dummy confusing and distracting the attacker while the cephalopod rapidly changes colour and is jet-propelled in another direction. The ink also seems to paralyse the attacker's sense of smell, giving the cephalopod an even better chance of escape.

The shell of the cuttlefish is a beautifully adapted structure that not only gives support to the soft body of the cuttlefish but also serves as a flotation device. Spaces within the 'bone' can be filled either with air or water, so changing the creature's density.

In most cephalopods the shell is a not very substantial structure, but in *Nautilus* it is well-developed and very beautiful. *Nautilus* lives on the floor of the Pacific Ocean feeding on shrimps and other small creatures. It is the only surviving cephalopod to have an external chambered shell. All the chambers of the shell, apart from the largest one in which the animal lives, are occupied by gas. The composition of this is similar to air but contains less oxygen. The gas buoys the shell up in the water so enabling the animal to swim freely unencumbered by the weight of the shell.

The paper nautilus *(Argonauta)* is one of the most extraordinary cephalopods. It is a strange octopus that swims in surface waters. The female may grow up to a foot in length. The male rarely exceeds half an inch! The shell carried by the female is not a true shell. It is produced by the broadened tips of the first two arms and its function is to shelter the eggs until the tiny argonauts are able to live on their own.

The humming bird hawk moth is a powerful flyer that at first sight can be mistaken for a humming bird. It has an enormously long tongue with which it is able to probe for nectar in the deepest flowers.

The largest group of animals are the insects with over a million known species at present. So many wonderful examples of adaptation are to be found amongst insects that a whole book could be written about them. There is only room to mention a few here.

One of the most beautiful examples is that of the humming-bird hawk moths, very powerful flyers that can be mistaken at first sight for humming birds as they hover at flowers whilst feeding during the daytime. To suck up nectar the long tongue which is usually coiled up underneath the head is unravelled by pumping blood into spaces within it. It unrolls just as a paper snake does when air is blown into it. In its unravelled state the tongue can reach the nectaries of the most deep-throated flowers for nectar. At such flowers only long-tongued insects can feed in this way.

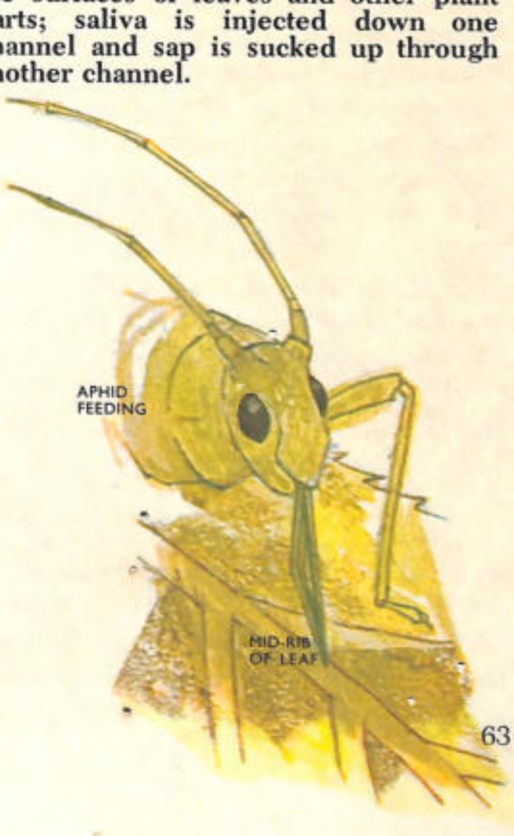
In contrast to the delicate sucking mouth of the humming-bird hawk moth are the hard biting jaws of the voracious little ladybird, a wolf in sheep's clothing. A ladybird may look pretty but as far as other insects such as greenfly are concerned it is a deadly enemy both as a larva and as an adult. The bright covers over its body are not wings but horny protective wing cases, characteristic of beetles. They are held out at right angles to the body when the beetle flies, in front of the hind wings which beat to propel the insect along.

Greenfly have mouthparts adapted for piercing plant tissues and sucking up the juices. A heavy infection of greenfly can severely weaken a plant. The two pairs of jaws are developed as fine needle-like bristles which surround two canals. When not in use they lie flat under the head partly sheathed in the lower lip. When the insect begins to feed the sheath is curved or partly withdrawn into the body and the needles are plunged into the host. Muscular action pumps up the sap of the plant into the mouth through one tube whilst saliva flows down the other and into the host. The saliva may help to digest the food.

Both the young stages and the adults of dragonflies are carnivorous, that is, they feed on other animals. A young dragonfly nymph has an unusual apparatus called a mask. It is a large hinged structure formed from the lower lip of the mouthparts. It is folded up under the head when

Ladybirds are predatory beetles equipped with hard, biting mouthparts. Both the adult and the larva are carnivorous.

Aphids have piercing and sucking mouthparts. The needle-like parts pierce the surfaces of leaves and other plant parts; saliva is injected down one channel and sap is sucked up through another channel.

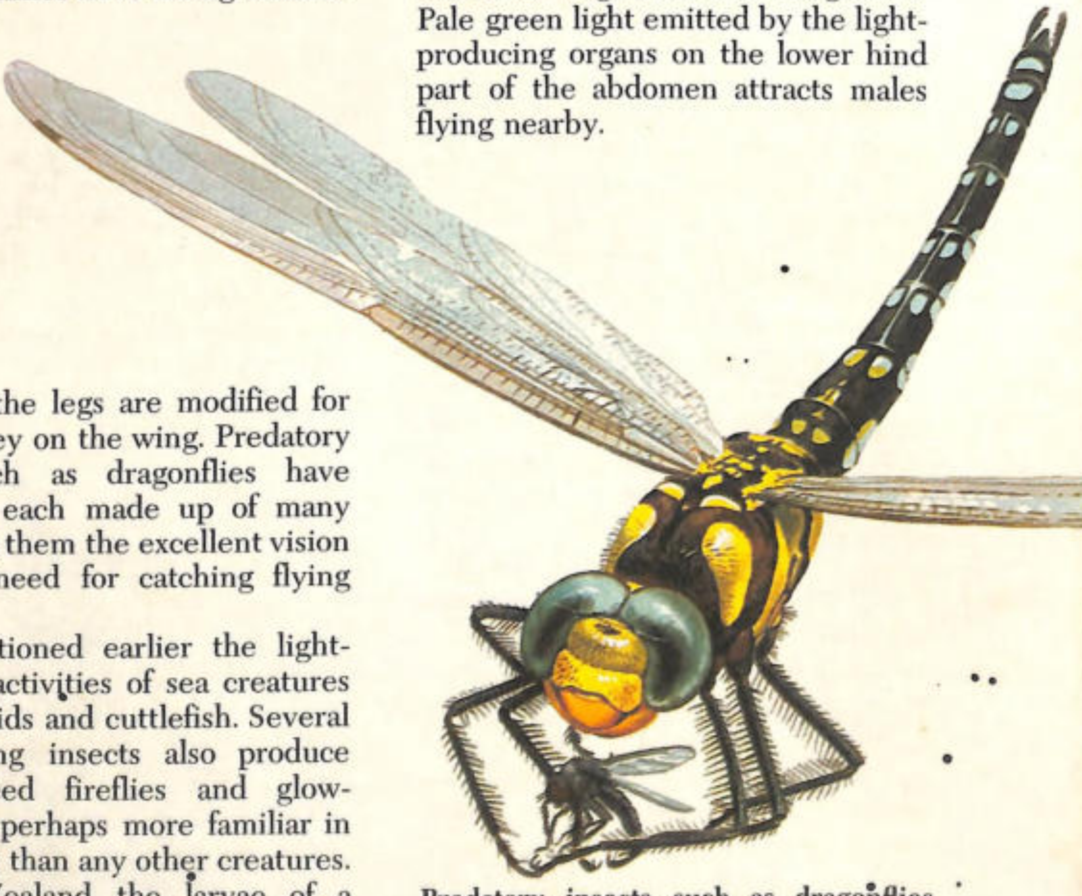


A dragonfly larva has a unique apparatus for catching food. It consists of a hinged underlip (mask) that folds up under the head when not in use. If prey approaches within catching distance then the mask is shot out and the prey, if caught, is impaled on the sharp pincer-like spines at the tip. (inset) An enlarged view of the head showing the mask.

not in use but can be unfolded and shot out to catch prey which are grasped or impaled by the sharp pincers at the end of the mask. Adult dragonflies have biting mouthparts, and the legs are modified for catching prey on the wing. Predatory insects such as dragonflies have large eyes each made up of many units giving them the excellent vision that they need for catching flying prey.

We mentioned earlier the light-producing activities of sea creatures such as squids and cuttlefish. Several land-dwelling insects also produce light. Indeed fireflies and glow-worms are perhaps more familiar in this respect than any other creatures. In New Zealand the larvae of a certain fly live on the ceilings of caves. Each glows and spins a web of luminous silk with which to trap food. The ceilings glow as if covered in thousands of tiny hanging chandeliers.

The glow-worm of Europe is a wingless female beetle (not a worm!) that lives in grass and in hedgerows. Pale green light emitted by the light-producing organs on the lower hind part of the abdomen attracts males flying nearby.



Predatory insects such as dragonflies have large eyes made up of many units, giving them the excellent vision that they require for catching prey on the wing. The front legs are adapted for grasping prey.

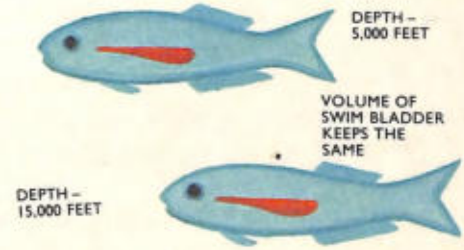
A click beetle showing the position of the light-producing organs.

A male firefly in the act of producing light with its photophores.

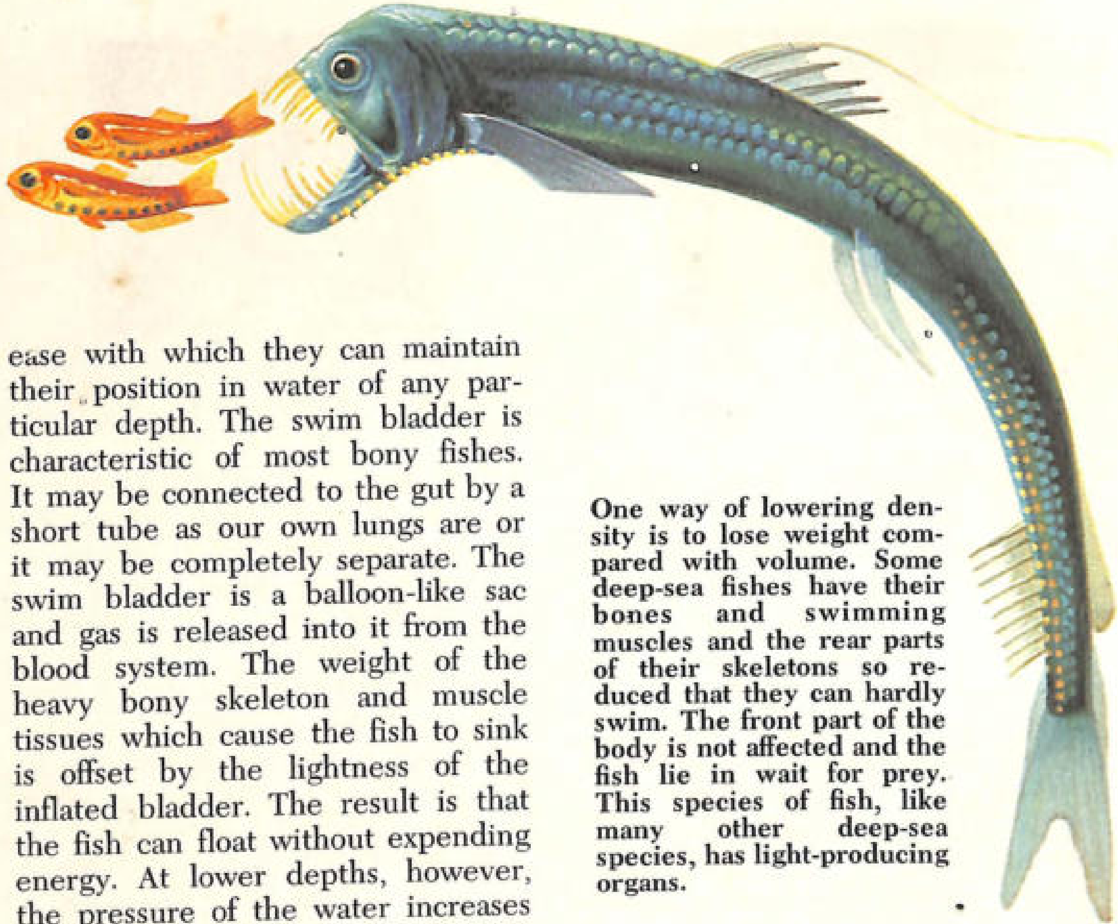
Pairing in fireflies depends on the exchange of light signals. The pattern of the signals differs from one species to another. In one species the male emits short flashes at short intervals. After a pause of about two seconds the female replies with a short flash. The male then flashes again, followed after a pause by a response from the female. There are several such exchanges of signals prior to pairing.

Some remarkable adaptations associated with obtaining oxygen are to be found in insects. The majority of insects live on land and have a well-developed system of breathing tubes for obtaining oxygen and distributing it to the tissues. Oxygen enters the tubes by way of paired openings along the sides of the insect's body. In some of the more active insects such as wasps actual movements of the body help to move the air in and out of the tracheae. Many insect larvae and some adults, however, live in water and cannot obtain their oxygen in this straightforward way. Some, such as the nymphs of mayflies, have special thin flaps of tissue called gills along either side of the body. These have a rich blood supply and extract oxygen from the water. Others, such as mosquito larvae, have special respiratory tubes which they are able to stick up through the surface film of the water in order to obtain oxygen. Amongst adult insects certain beetles and bugs are perhaps the most interesting. They collect air at the surface film every so often and carry it around with them under the water as a reservoir of oxygen. This reservoir may be held in place by means of special hairs or by means of the wing cases. Besides serving as an oxygen supply the bubble buoys the insect up in the water thus serving as a hydrostatic device.

Fishes too show many adaptations connected with increasing their buoyancy and so with increasing the



Some fish lower their density by inflating bladders within their bodies. Water pressure increases with depth; the effect is to compress the gas in the bladder. But more gas is secreted, keeping the fish at the same volume and hence at the same density.



One way of lowering density is to lose weight compared with volume. Some deep-sea fishes have their bones and swimming muscles and the rear parts of their skeletons so reduced that they can hardly swim. The front part of the body is not affected and the fish lie in wait for prey. This species of fish, like many other deep-sea species, has light-producing organs.

ease with which they can maintain their position in water of any particular depth. The swim bladder is characteristic of most bony fishes. It may be connected to the gut by a short tube as our own lungs are or it may be completely separate. The swim bladder is a balloon-like sac and gas is released into it from the blood system. The weight of the heavy bony skeleton and muscle tissues which cause the fish to sink is offset by the lightness of the inflated bladder. The result is that the fish can float without expending energy. At lower depths, however, the pressure of the water increases and the gas inside the bladder is compressed; the volume of the fish is lowered and its density is increased. Counteracting this effect, more gas is absorbed by the bladder, so keeping the gas at a constant volume. The gas pressure may rise inside the sac to an enormous degree. For instance, fish swimming at fifteen thousand feet need a pressure of seven thousand pounds per square inch inside the bladder tc withstand the sea's pressure!

Not all fish have swim bladders. The sharks and their allies constantly swim in order to keep up and are not nearly so stable. Of the bony fish those that live on the bottom, such as plaice, have lost their swim bladders altogether in the course of evolution as have fast swimmers such as mackerel. The reason underlines one of the drawbacks of the swim bladder as a hydrostatic organ. In changing its volume according to the depth at which the fish is swimming, some length of time is required. The release and absorption of gas is a delicate operation. A fish caught in a trawl net that is rapidly brought to the surface will burst, causing damage to the other internal organs. Consequently mackerel, though they must swim to keep afloat, nevertheless may move rapidly from one level of the ocean to another.

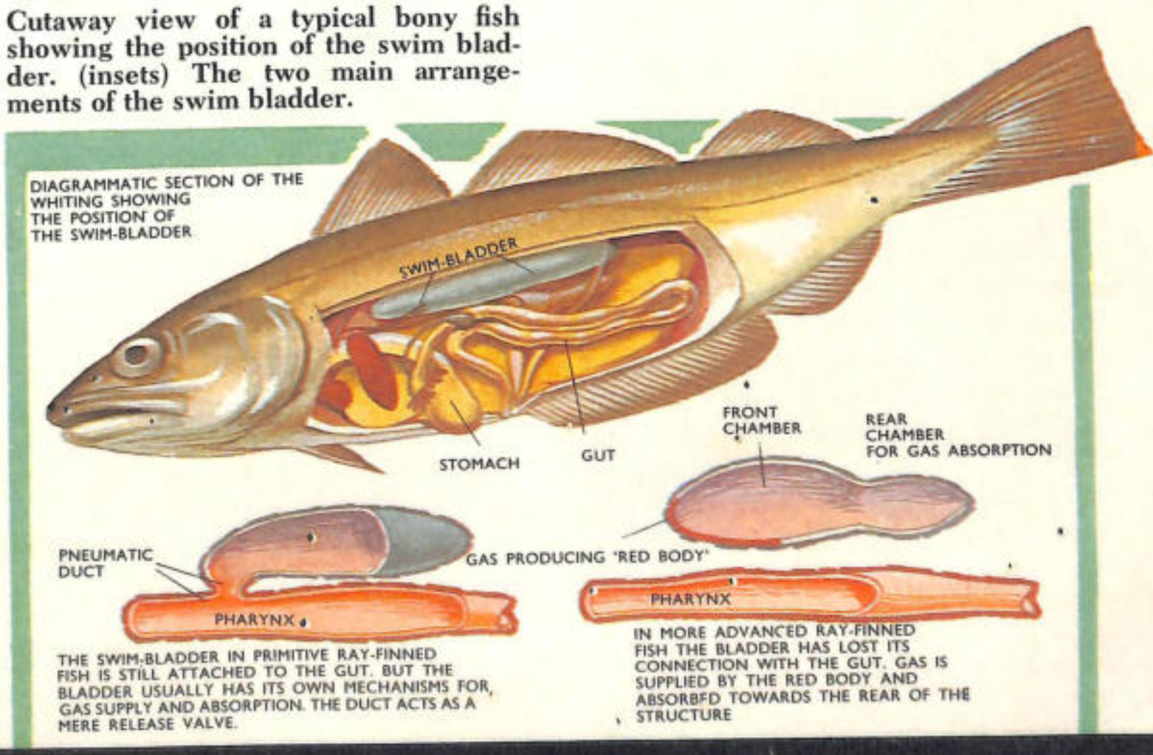
Another means of lowering the density is to dispense with as much as possible of heavy tissues. Thus some bottom-dwelling ocean fishes have a much reduced skeleton in the tail region. The swimming muscles are poorly developed and appear delicate, almost transparent. The proportion of dilute body fluids and fatty tissues is high and the body density is just less than that of water.

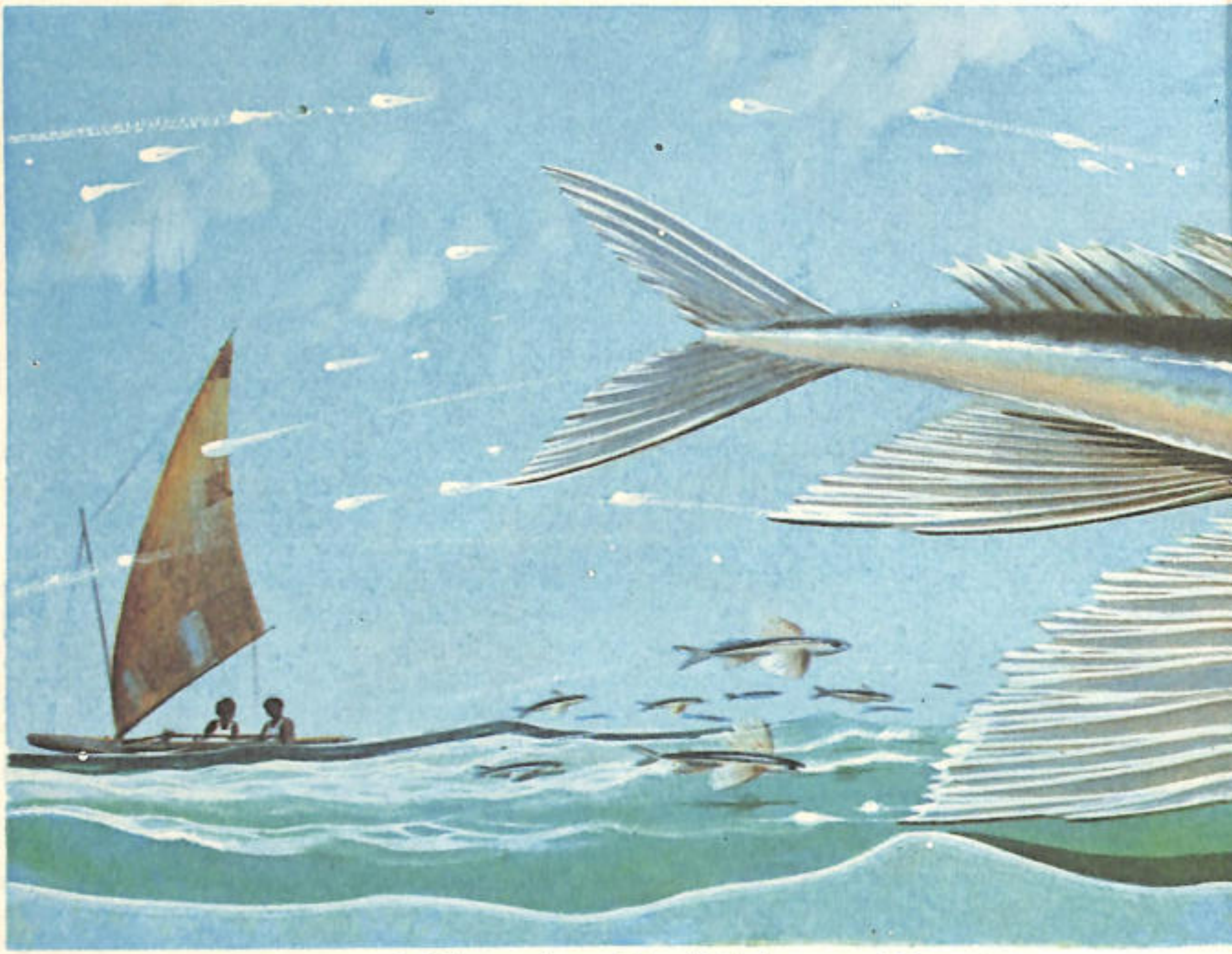
Among the cephalopods the buoyancy adaptations of *Nautilus*, with its delicate chambered shell, and of the cuttlefish have been mentioned. Another variation is to be found in deep-water squids, allies of the cuttlefishes. These squids have solid chitinous internal shells which, though acting as a skeleton, have no hydrostatic function. What then is the answer to the riddle of how the squids manage to float at all levels? The answer rests in their body fluids, for these have a density below that of the water in which squids swim. The density is low because of the presence of ammonia in a special form in solution, ammonia being the chief nitrogen-containing waste material produced by the chemical reactions proceeding in the squids' tissues.

Apart from the methods mentioned so far of keeping afloat, others are to be found among the vast numbers of single-celled animals that form a part of plankton in the sea—plankton is the floating and drifting life carried about by currents as distinct from the active strong-swimming creatures such as fishes and squids. Some have a density less than that of the water as deep-sea squids do. Others have a very large surface area for their size and may be flattened, ribbon-shaped or drawn out into long slender spines. The larger an organism's surface area relative to its volume the greater will be its resistance to sinking due to the high level of friction between it and the water. Many tropical planktonic creatures have numerous delicate spines and feathery projections, far more than their temperate water counterparts which are living in colder, denser water. The fact that polar water is denser than tropical water may partly account for the extraordinary fact that polar sea creatures generally are larger than their tropical cousins. They can afford to have a larger volume relative to their surface area.

The Portuguese man-o'-war *(Physalia)* has an enormous air sac which floats above the waves, supporting

Cutaway view of a typical bony fish showing the position of the swim bladder. (insets) The two main arrangements of the swim bladder.



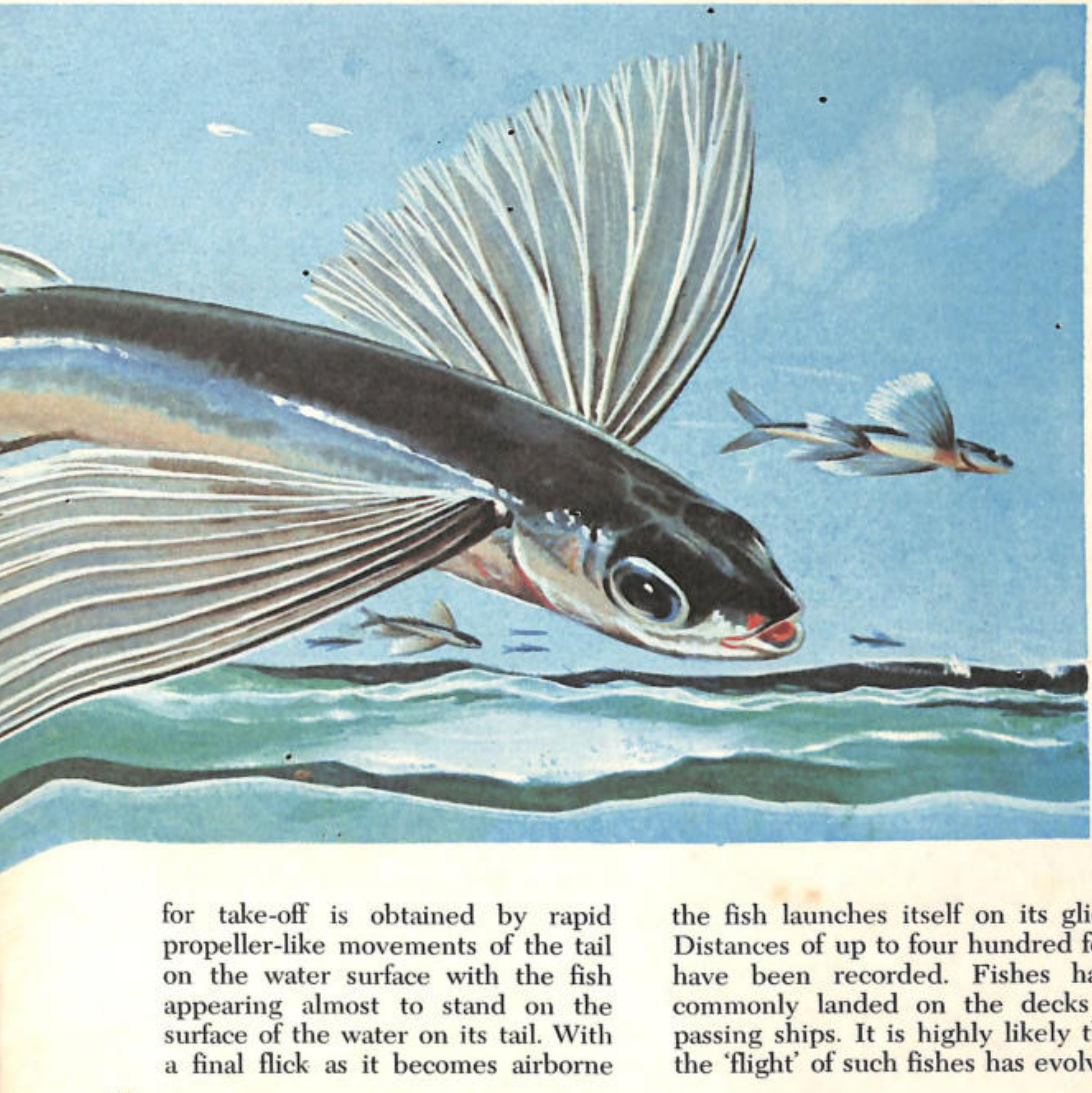


Flying fishes have large, expanded breast fins with which they are able to glide for considerable distances over the sea surface.

the rest of the creature which hangs beneath the surface (see page 34). Occasionally favourable currents from the Bay of Biscay carry incredible numbers of these onto the beaches of the south coast of Britain. These extraordinary creatures sometimes have tentacles maybe several feet in length. They carry an armoury of stinging cells that can cause irritation to the human skin greater than that due to a stinging nettle.

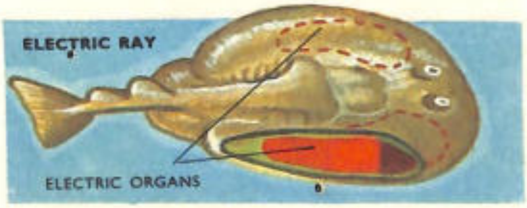
A similar device to the air bladder of *Physalia* is used by *Ianthina,* a floating snail. It actually makes its own raft of bubbles made up from gas and slime which the snail produces.

One of the most unusual fishes is the flying fish of which there are several species. The breast fins of these fishes are large wing-like structures on which the fish are able to glide for considerable distances. The 'wings' are not flapped at all during the glide so that the fish is not strictly able to fly, but merely uses its fins as parachutes. The speed



for take-off is obtained by rapid propeller-like movements of the tail on the water surface with the fish appearing almost to stand on the surface of the water on its tail. With a final flick as it becomes airborne the fish launches itself on its glide. Distances of up to four hundred feet have been recorded. Fishes have commonly landed on the decks of passing ships. It is highly likely that the 'flight' of such fishes has evolved

Drawings of an electric eel and an electric ray showing the positions and relative sizes of the electric organs. The ray has large kidney-shaped organs in its pectoral fins, whilst much of the hind part of the eel's body is taken up by the long, column-shaped electric organs.



The North American spadefoot toad has a horny projection or 'spade' on its rear legs which enable it to dig in mud to gain protection from the hot sun. (right) The chameleon has a long tongue which it can flick out at great speed to trap unwary insects.

as a means of escape from other carnivorous fishes. Flying fishes spend most of their time near the surface feeding on small fish and shrimp-like creatures.

The bee humming bird has a long, curved bill ideally suited for probing for nectar in deep-throated flowers.

Many of the processes in the body produce electrical changes which can be measured. Special machines have been devised for instance to measure the electrical waves produced by the human brain. The fact that animals produce electricity was first discovered in the electric fishes. Their powers of generating electricity far surpass those of other living organisms. The electricity that they produce is used for navigation, or for defensive or offensive purposes. The giant electric ray can produce a current of fifty amperes at an electrical pressure of over fifty volts, enough to kill large fish. The electric eel of South American rivers can give a shock of several hundred volts. Some other species of fishes, elephant-snout fish, produce less strong electric currents at electrical pressures of from a tenth of a volt to a few volts. Nevertheless, this is of great use to the fish as a navigation system in their murky surroundings and also for detecting prey and enemies.

In most cases the electric organs are formed from muscle fibres which are modified in the young developing animal or embryo as it is called. The

Bills of the kiwi, macaw and skimmer.

organs of the electric catfish, however, are modified skin glands.

The tail region of the electric eel makes up over four-fifths of the fish and well over half of this consists of electric organ. The organ is made up of numerous special cells which are large and flattened. The cells are piled one on the other in long columns rather like the cells of an accumulator. The eel has as many as seventy columns of cells running the length of the body on either side, with up to ten thousand electric cells in each. The cells are arranged in series enabling a large voltage to be built up, but since the columns are themselves arranged in parallel a large current can also be produced. This enables the eel to overcome the high electrical resistance of its freshwater surroundings and still deliver a considerable shock. Salt-water fishes have fewer electric cells, a fact which is probably associated with the lower resistance of salt water.

The electric organ of the electric eel is made up of three parts, each able to deliver a shock of different intensity. The organs of the electric skate are situated in the tail, but in the electric ray they are kidney-

The flamingo is a unique feeder. When the bent beak is immersed in the water, the top bill becomes bottom-most. Water is pumped by the lower bill through slits in the upper bill. The tongue filters food out of the water.

shaped organs in the breast or pectoral fins. Those of the electric catfish form a 'sleeve' around the middle region of the body, under the skin surface.

More intriguing perhaps than the production of large shocks is the recent discovery that several fishes produce weak electric fields which they use for navigation purposes. It seems that they employ an electrical guidance system after the manner of bats, which use high-frequency sound waves. The frequency of the electrical waves varies from about twenty-five per second in a species of eel to fifteen hundred per second in the knife fishes of America. Besides being able to generate electricity, these weakly electric fishes can detect changes in the electric fields that they produce with special sense organs. The latter have yet to be identified, but when nerve fibres to the brain are cut the fishes are unable to detect metallic objects placed in the water, as they would do normally. Many fishes move away from objects that they are able to detect but others attack metallic objects with great ferocity. Apart from this use for navigation, therefore, the emitting and receiving system would appear to have offensive and defensive uses as well.

The spade-foot toad of North America is adapted to living in desert conditions. It has a horny pad on its rear foot for burrowing in mud during drought. Puddles quickly dry up. These toads must breed quickly, and

Bullfinches have the short, stout beak characteristic of finches and other seed-eating birds. The beak is also admirably suited to nipping the scales off buds to expose the young succulent contents. Bullfinches play havoc with fruit crops in many parts of the country because of this destructive habit.

when the water evaporates parents and young burrow in the mud to avoid the heat.

Chameleons are noted for many features. One of the most intriguing is the long tongue which can be shot out a considerable distance to trap insects which are deftly passed back into the mouth.

Birds come into our lives perhaps to a greater extent than any other creatures. Their most obvious adaptations concern flying and feeding. For feeding the beaks and feet of birds exhibit many wonderful adaptations, modifications that are put to an extraordinary variety of uses. The buzzard's beak is sharp-edged, hooked and powerful. It is a vicious instrument ideal for tearing flesh from carcasses. But such a beak is useless for fishing. The heron, on the other hand, with its long, sturdy

The Central American king vulture with the remains of a meal. Vultures have large, powerful hooked beaks typical of many scavenging birds, though marabou and crows have long, straight beaks.

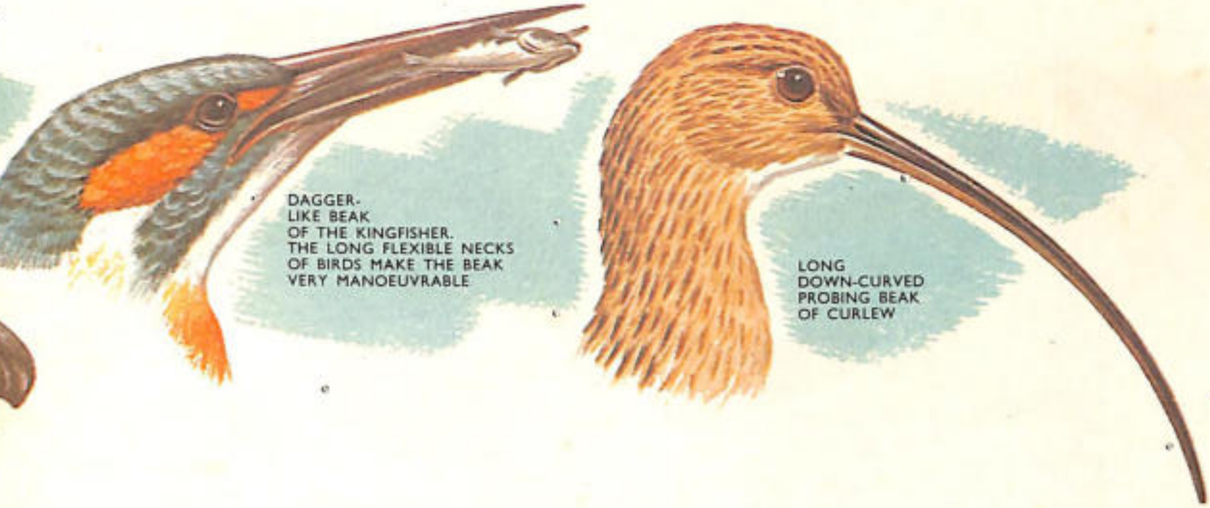
Why the toucan's bill should be quite as long is something of a mystery. Certainly the bird's reach is considerably extended. The bill, made of horny skin covering a delicate meshwork of bone, is not as heavy as it looks.

bill, is an excellent fisherman. For hours it may stand motionless and then with a rapid stab an unwary fish is captured.

The earliest birds that lived some 150 million years ago had no beaks; their jaws were equipped with teeth just like their reptilian ancestors. But today's birds have no teeth and have a horny beak instead. The beak is not a complete substitute for teeth. Though used for biting, tearing, or cracking seeds, most mastication of the food takes place internally. But the beak has largely taken the place of forelimbs. In birds these are adapted as wings. They no longer can be used for grasping, clutching, or conveying food to the mouth. The beak, sometimes with the help of the feet, must do the necessary probing, holding and plucking; it must also be used for personal cleaning and grooming as well as carrying out such functions as nest-building and feeding the young.

The design of the beak reflects the predominant diet of the bird in question. As the food consumed by birds is so variable—from the flesh

Heads and beaks of the rook and falcon. The former is an all-purpose beak useful for eating a wide variety of foods. The hooked beak of the falcon is typical of a flesh-eating bird.



Heads and beaks of the shoveller duck (left), kingfisher (centre) and the curlew (right).

of other animals to the nectar of flowers – so the variety of beaks is correspondingly enormous. Specialised hunting birds have sharp, hooked beaks suitable for tearing flesh. The buzzard has already been mentioned. Other flesh-eaters are the eagles, hawks, falcons and owls. Scavenging birds such as vultures may also have hooked beaks; alternatively the beak may be long and stout as in crows and marabou. Fish-eating birds such as the kingfisher, guillemots and the gannet are equipped with a long, dagger-like beak. Beneath the long tapering beak of the pelican loose skin of the throat can be distended into a dip-net for receiving fish. The oyster-catcher has a long blunt, vertically flattened bill well adapted to opening oysters, probing in mud or prising limpets from rocks.

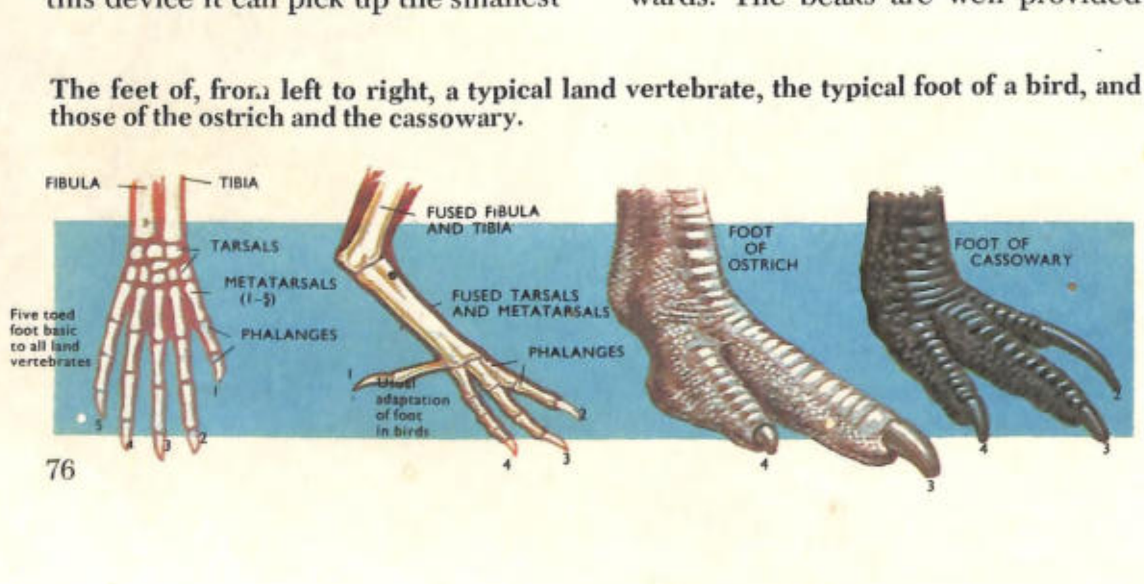
The ostrich is the largest living bird having two toes on each foot. The feet are adapted for fast movement across open grassland and are also powerful defensive weapons. The stubby beak is not particularly specialised. The ostrich's diet includes insects, small rodents, lizards, and fruit, seeds and other plant parts. ▶

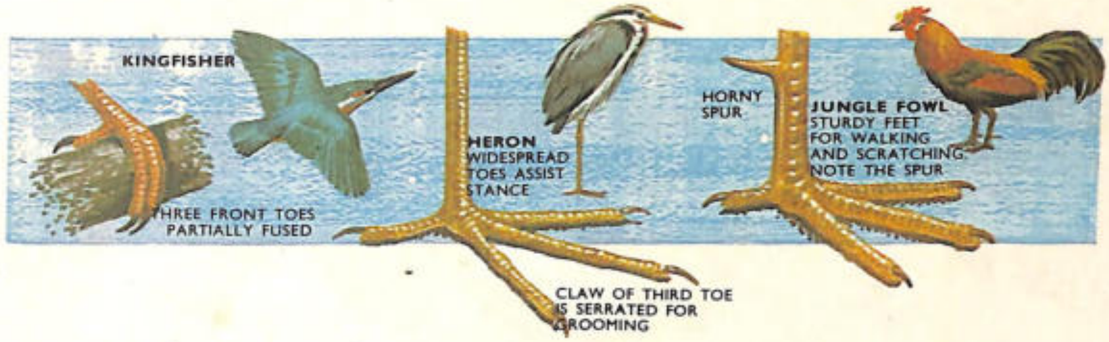
The jacanas or lily trotters have extremely long toes that enable them to walk over floating vegetation without sinking, as their weight is distributed over a relatively large area.

Seed-eating birds such as finches, buntings and siskins have short, thick, strong beaks. Hard outer seed cases may have to be cracked, for which the stout beaks exert great pressure just like the area near the hinge of a pair of nutcrackers. These beaks are also excellent for nipping off young buds. Another seed-eater, the crossbill, has the upper and lower halves of its bill overlapping. With this device it can pick up the smallest seeds without difficulty. Blackbirds, thrushes, starlings and many other birds have moderately long beaks. They are not long enough for fishing but adequate for probing for worms, eating molluscs and grubs, and pecking at soft fruits.

Wading birds that probe for worms and molluscs in soft mud flats have long beaks which are flattened sideways and sometimes curved downwards. The beaks are well provided

The feet of, from left to right, a typical land vertebrate, the typical foot of a bird, and those of the ostrich and the cassowary.





(from left to right) The feet of a kingfisher, heron, and jungle fowl. Kingfishers have the first three toes partly joined, forming a scoop-like structure excellent for digging nests. The widespread toes of the heron assist its stance. The jungle fowl has sturdy feet for scratching about.

with nerves at the tips and are very sensitive. Characteristic waders are the sandpipers, redshanks, greenshanks and curlews.

Ducks have broad beaks, flattened downwards and deeply grooved inside; they are used for sifting worms and small aquatic animals from mud and water, but will also devour herbage, grain and berries. An extreme example of the sifting type of bill is found in the shovellers. Such birds have large, flattened spatulate beaks that are provided with a fringe of bristle-like structures along the edge. These retain edible material as mud is squeezed from the bill. The spoonbills have spatulate tips to their flattened beaks. These birds wade along with the beak half-immersed in water snapping up anything edible.

Flamingoes have a unique feeding mechanism. Their beaks are curved right over so that when immersed in the water the top bill is bottommost. The pumping action of the lower bill drives mud and water through slits in the top bill. Small edible creatures—algae, worms, crustaceans—are filtered out by tooth-like projections from the tongue.

Avocets are noted for their long strongly upturned bills. They wade along, with jaws open, sweeping the bill from side to side either at the surface of the water or near the bottom. Small invertebrate creatures are consumed and also small fishes and amphibians.

The woodpeckers have long, strong chisel-like beaks. The beak actually bores into the bark of trees and a long, protrusible tongue laps up the exposed insects. Tree-creepers also have long beaks but they are much feebler. They do not attack the bark but only probe in its crevices.

The placental and the marsupial mole both have well-developed snouts and powerful claws, giving them a remarkably similar appearance for two unrelated creatures. They are each suited for an underground, burrowing existence.

(left) The great anteater is a creature beautifully adapted for feeding off ants: its long tubular snout for routing out ants that it has unearthed with its powerful front claws and a long tongue for licking up the ants as they scurry out of their disturbed nest. (centre) The two-toed sloth is adapted for life in trees. (right) Nocturnal creatures often have large eyes.

Humming-birds have a diet of nectar. Their beaks, which often curve downwards, are slender and thin. They vary in length according to the size of flowers visited. The humming-bird hovers motionless over a flower and inserts its beak inside the petals. The tongue, which can be extended beyond the tip of the beak, either has a tubular tip for sucking or is brushy.

Toucans have enormous beaks and the cutting edges are serrated. Their diet consists of succulent fruits. Certainly the length of the beak helps the bird reach out for inaccessible fruit, but need it be quite the size it is? One theory is that the beak evolved for eating some fruit that no longer exists. Perhaps it is used in courtship displays or as a recognition mark between the species.

Contrasting in size are the minute beaks of the swallows, swifts and nightjars. These birds catch insects on the wing, flying forwards with their mouths held wide open. No probing is necessary and the function of the beak is relegated to grooming, though it is of considerable use in the construction of the nest in the case of swallows.

One bird, the woodpecker finch of the Galapagos Archipelago, uses its beak for handling a tool—just as Man uses his hands for manipulating a variety of instruments. The 'tool' of

The kangaroo has a powerful pair of hind legs enabling it to move at high speed over its grassland home.

this extraordinary finch is a cactus spine; with it insects are probed from beneath the bark of trees.

Feet, as well as beaks, show great variety in birds. The feet may be adapted for swimming, walking, climbing, perching or catching food according to the bird's mode of life.

Most birds have feet with four toes. The first (big) toe is usually turned towards the rear. Working in opposition to the other three it provides an excellent mechanism for perching, or in the case of the flesh-eating birds for grasping and carrying prey. Alternatively the backward-pointing toe may be very long and straight as in larks and wagtails. These birds spend a lot of time running over flat ground, and the long toe helps their stance.

The large flightless birds, in the majority of cases, have lost their first toes. They do not need a perching

Giraffes have long necks for feeding off the uppermost leaves of trees.

(left) The humps of the camel are not water tanks but stores of fat which enable the camel to go long periods without eating. Water is released from the fat when it is burnt by the tissues. (right) The musk ox is adapted for life in the cold Arctic; its long fur helping it to withstand the bitter winds of the Arctic winter.

foot of any kind. An example is the Australian cassowary. The eight foot tall ostrich, largest of living birds, has only two toes on each foot, the third and fourth, and runs about on these. The condition might be compared with that of the hoofed mammals which run about on the tips of their toes which are reduced in number.

In woodpeckers, cuckoos, parrots and toucans, the fourth toe as well as the first may be turned backwards. The result is a strong, stable climbing and perching mechanism which can also be used for feeding purposes. Owls, rollers and the osprey have a flexible fourth toe which, though normally facing forwards, can also be turned backwards.

Kingfishers, matmots, and the West Indian todies have all three front toes partly joined; a scoop-like structure is formed, excellent for digging nests in the ground.

Water birds engaged in swimming and diving may have flaps of skin between the toes, forming a webbed foot. The webbed feet act as paddles

The flying squirrel has a large parachute-like membrane on either side of its body between the limbs, with which it is able to glide considerable distances from tree to tree.

presenting a large surface area to push against the water. They may also be used for steering.

Usually only the front three toes are webbed and the hind toe is reduced in size as in ducks and geese. But some web-footed birds—cormorants and pelicans for instance—have the first toe brought into a forward position and it too is webbed.

Birds with webbed feet are clumsy and ungainly walkers on land. Coots, grebes and phalaropes, instead of a web, have each of the three toes provided with a scalloped fringe of skin. This extra surface facilitates swimming but, because each toe is free, the birds can walk equally well.

Perhaps the best swimmers of all are the divers and grebes. The divers' and the grebes' feet are set far back on the body, just as the propellers of a launch are at the rear. In the diver, only the feet project beyond the body.

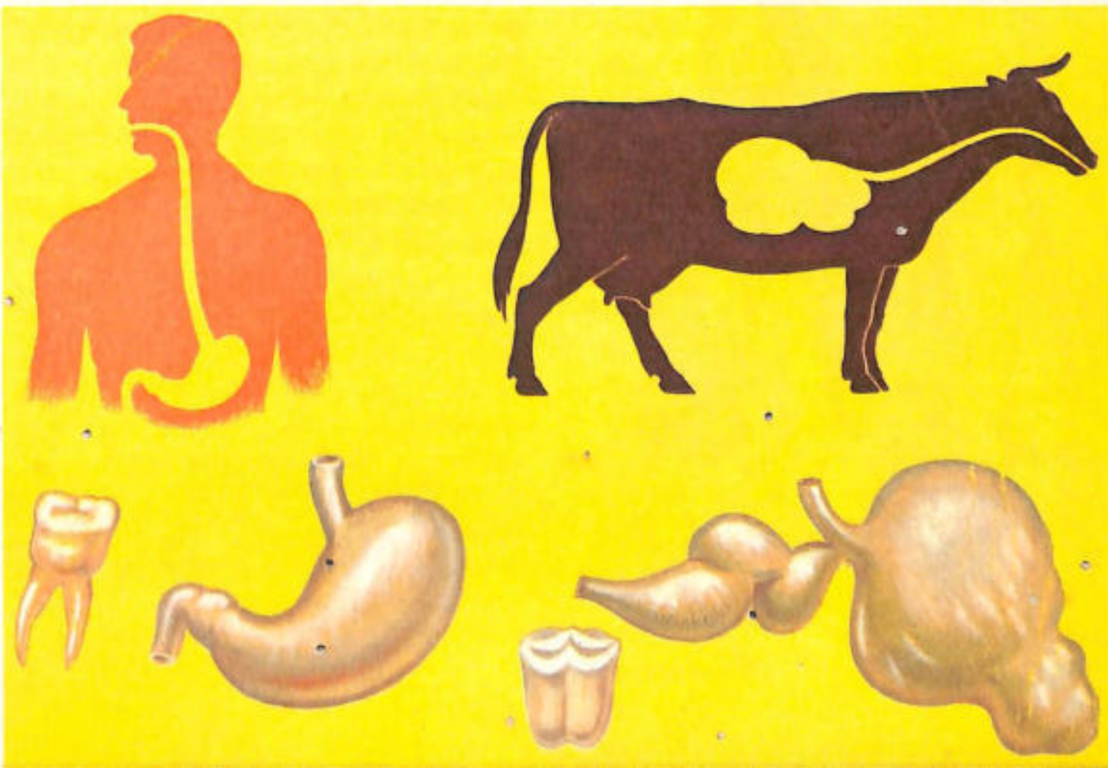
Birds that walk over soft mud flats tend to have long toes, well spread out so that weight is evenly distributed. The heron and the curlew are examples. The jacanas or lily trotters have particularly long toes and are able to walk unconcernedly over floating leaves.

Chickens and game birds spend a lot of time on the ground scratching about for food. The feet are sturdy with three strong toes in front; the hind toe usually remains small. The toes have blunt claws for scratching, though some have a horny spur for fighting. Ptarmigan or Arctic grouse have their toes covered in warm feathers.

The claw of the middle toe of a few birds—herons, bitterns, owls and nightjars—has a comb-like serrated edge for grooming and removing slime from feathers.

Some remarkable adaptations are to be found among mammals. Both the placental and the marsupial moles, which live similar lives, have long snouts and powerful claws for digging underground tunnels. The

Diagrams comparing the structure of the teeth and gut of a cow and man. The cow has a many-chambered stomach for digesting the large amounts of plant food that it consumes.



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kangaroo has enormously powerful hind legs that give it the drive needed for its peculiar method of moving. The large tail is a balancing organ while the kangaroo is moving and serves as a prop to sit on while it is stationary.

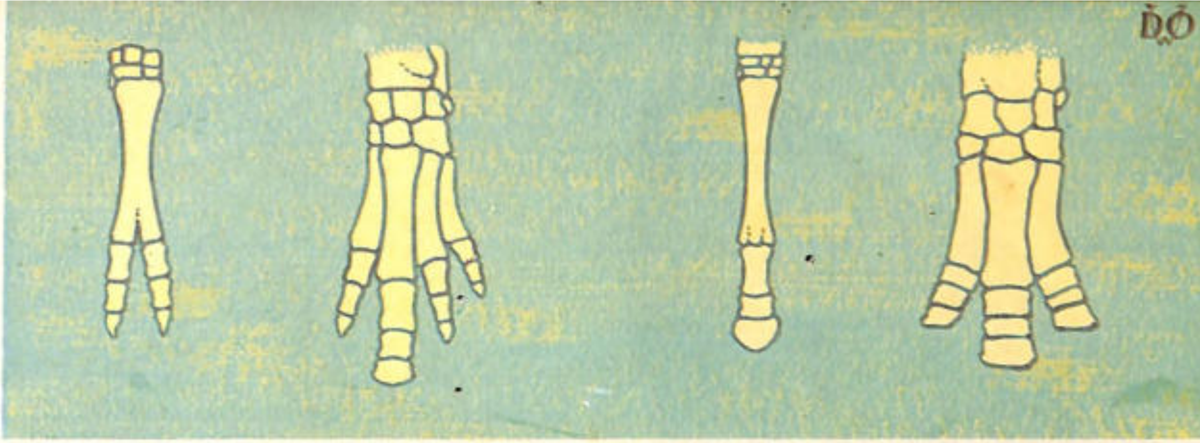
The great anteater is an incredible creature with its enormous bushy tail and its long toothless snout. The latter is used as a probe for ants on which the anteater feeds exclusively. It has a very long tongue for licking up ants, and the claws on its front feet are so long that it cannot walk on the soles of its feet.

The sloths are adapted for life in the trees. They have long limbs and the toes bear claws for hanging upside down from the branches of trees, in their native rain forests of South and Central America. It is highly likely that earlier sloths were insect-eating but today's species live on foliage.

The giraffe's neck is perhaps the most familiar example of adaptation. A bull giraffe may reach a height of fully nineteen feet and consequently can reach higher for feeding purposes than any other hoofed herbivore. But the great length of its legs and neck poses problems for it when it wishes to drink at a waterhole. It has to splay its legs out in a rather ungainly way while it bends the neck over in a great semi-circle.

The camel's hump is not a water tank as popular stories would have it.

◀ **Diagrams illustrating the relative proportions of the various limb bones in the leg of a horse and man. (insets) Diagrams comparing the structure of a human nail with the hoof of a horse.**



The foot structure of various hoofed animals. (from left to right) Those of the camel, horse, tapir and rhinoceros.

It is a store of fat which enables the camel to overcome periods of food shortage. But fat when it is burnt to supply energy releases quantities of water, so that indirectly it does provide the camel with water for its internal workings.

The musk oxen is one of the few large mammals to inhabit the Arctic tundra. Its long coat provides protection against the bitter cold of the Arctic winter. Its strong odour and its habit of forming defensive formations protects it against enemies such as the wolf. Its cloven feet are splayed to help it walk over the soft snow.

The feet of mammals are adapted in various ways. Coypus and beavers have webbed feet to prevent them from sinking in mud, and to help them swim. Burrowing kinds, such as pocket gophers, have large claws for digging and tree-living rodents use their long claws to help them grasp the smooth trunks and branches of trees. The legs of kangaroo rats are very long, ideal for jumping over the loose sand which is their home.

Flying squirrels have a parachute-like membrane stretching between their fore- and hind-limbs on either side of their bodies. This enables them to move about in their forest home from tree to tree at incredible speed.

The hoofs of many mammals are good examples of adaptation. We shall come to these in a moment. First let us look inside a hoofed animal such as the cow, for there are also internal adaptations to mode of life besides obvious external ones. A human being eats all kinds of food and does not need to eat very much in order to extract sufficient fuel for his requirements. He has a simple sac-like stomach and his teeth are not specialised. But a cow eats plant food, principally grass, in enormous quantities. Its teeth are very specialised and form at the front a sharp, chisel-like surface for cropping grass, whilst at the back the teeth are enormous ridged structures suited to grinding up large quantities of grass. A cow does not chew its food very thoroughly in the first instance but swallows it fairly rapidly. It passes into the first stomach. But later this half-chewed food is regurgitated into the mouth where it is chewed more thoroughly. It is then swallowed again and passes into the other chambers of the stomach – there are four in all – and there the food is acted on by bacteria which break it down into substances that can be used by the cow. Grass consists mostly of a

The walrus has enormous upper canine teeth with which it digs up the molluscs on which it feeds.

starch-like substance called cellulose which cannot be broken down by the digestive enzymes that the cow itself possesses, so it must rely on the activities of numerous bacteria in its stomachs.

Man walks about on the soles of his feet, but in the hoofed animals the limbs are lengthened and raised up on the toes, of which there are often only one or two remaining, as in the horse and the cow respectively. Hoofed animals are basically unaggressive creatures. During the course of evolution many such creatures have adopted a swift method of moving as a means of escape from enemies. This has been made possible by the unique tiptoeing action of the limbs.

The walrus has long and prominent upper canine teeth adapted for digging up the molluscs on which it feeds. The walrus is only semi-aquatic, spending long periods on land. The whales and porpoises on the other hand are fully aquatic and have a fish-like streamlined form. They still breathe air, however, and have to come to the surface to breathe periodically. Some have been known to stay under for an hour without surfacing, showing how large a store they are able to take under with them. The skin contains a thick layer of fat—the blubber—and this acts as insulation against heat loss.

Whales are fish-like mammals beautifully adapted for a life that is wholly spent in water. (upper left) A killer whale, like the porpoises (upper right), is a whale that has teeth, and (lower left) a humpback whale and a blue whale (lower right), whales that have a special apparatus of baleen plates for straining plankton from the water. Behind the blue whale is another toothed whale, the sperm whale, which feeds predominantly on squids and other cephalopods.

CHAPTER 7

Plant adaptations

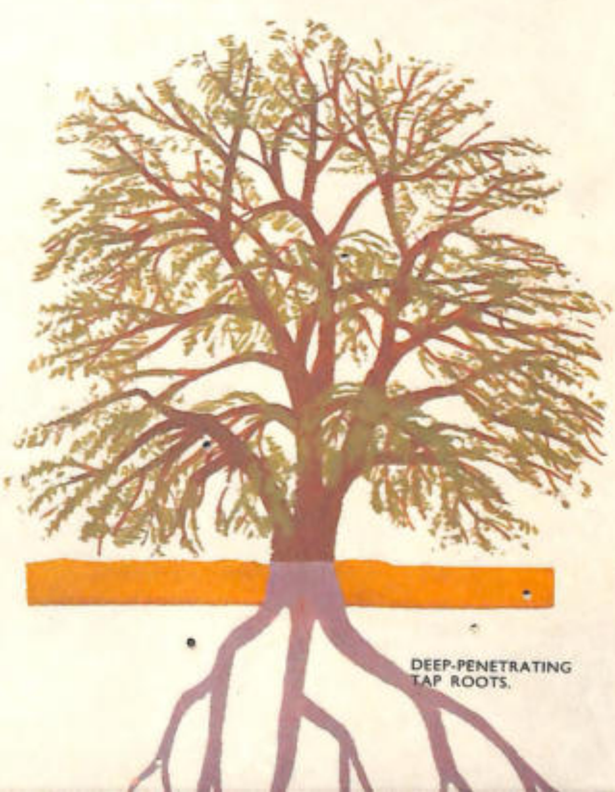
PLANTS, like animals, exhibit many modifications that suit them for life in their own surroundings. Some, living in marshy situations, are able to trap insects in order to supplement their ordinary 'diet'. Others, living in very dry conditions, can obtain and conserve sufficient water to grow and reproduce. Many plants have prickles or spines that have a protective role.

Many desert plants survive droughts as resistant seeds with tough, protective coats. When rain eventually does fall, the seeds quickly germinate. These plants are called drought evaders. They avoid the problem of water shortage—and have no special adaptations such as wax-coated leaves, water-storage tissue or deeply penetrating roots. Growth is rapid, flowers are produced and more seeds form. The cycle is over in less than six weeks. Perennial plants likewise flourish during the rare rainy spells, but for the rest of the time they must endure the harsh, dry climate. They are drought endurers. Any water that does become available must be absorbed and conserved. Many different adaptations are found to do this.

The cacti of American deserts are great hoarders of water. When moisture is plentiful, it is quickly taken up by the shallow, widespread cactus roots. The stem of the plant is used for storage, the pleated surface filling out as the water is absorbed. As in many desert plants the leaves are absent, so reducing

Many shrubs and cacti absorb water over a wide area by means of shallow, spreading roots.

The large desert trees obtain water using long tap-roots that penetrate deep below the surface.



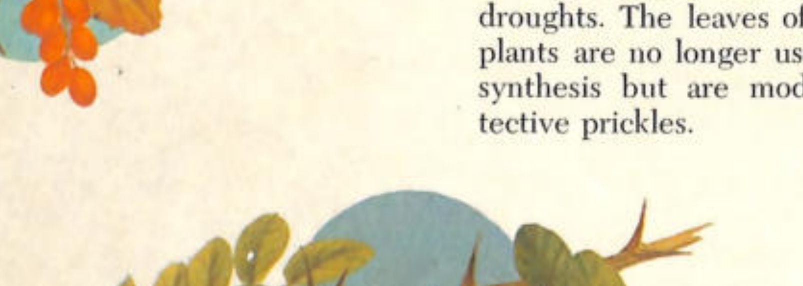
The illustrations show various plants in which the spines are modifications of leaves. As a rule, spines are plant adaptations to dry conditions and have only a secondary protective value.

the surface area through which water can be lost. The plant makes its food in the surface cells of the stem. The spines of cacti, which are stem outgrowths, discourage browsing animals from destroying the plants for the sake of their water supply.

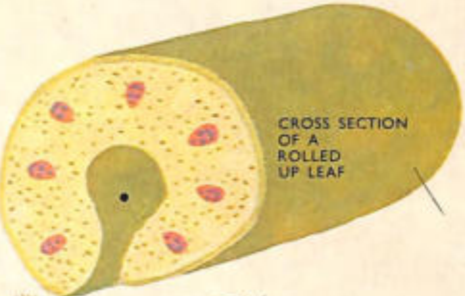
Trees such as the mesquite of America and the acacia of Africa have a very deep tap root. It may penetrate to a depth of a hundred feet or more in search of moisture. With a reasonable supply of water assured, the leaves are often found to be unprotected against water loss.

Smaller shrubs have shallow, widespread roots, deep tap roots or both. Because the competition for water is strong they are usually found well separated from each other. The leaves are sparsely distributed and are often coated with wax so that excessive water loss through evaporation is restricted.

The paloverde tree of Africa has leaves less than a millimetre across and even these small structures tend to drop off the branches in severe droughts. The leaves of some desert plants are no longer used for photosynthesis but are modified as protective prickles.



Leaves may roll up into tubes, so reducing the area from which water can be lost. The leaf pores open into the hollow chamber formed by the rolled-up leaf.



About a third of all desert perennials store water in underground structures—roots, rhizomes, bulbs, tubers and swellings called nodules. The plant structures above ground die off in very dry weather, leaving their portions underground to produce new flowers and seeds when the rain returns.

Some plants are carefully avoided by Man and animals. They are equipped with tough, sharp-pointed structures capable of inflicting irritating, even painful, wounds. These are the prickles, needles, thorns and spines of everyday language. Not all spines are derived from the same structures. Those of hawthorn and sloe are sharp, woody structures that in reality are dwarf branches. In most other cases the leaves themselves are modified. The barberry, for instance, has some of its leaves replaced by long spines. Gooseberry bushes are spiny because of sharp, pointed outgrowths from the leaf-base. In the false acacia the stipules, usually tiny outgrowths at the base of a leaf stalk, are modified into spines. In holly and thistle the margins of the leaves are drawn out into spines.

The thorns of the blackberry and bramble are outgrowths of the stem known as emergences. Spines covering cacti are simply outgrowths of the 'skin'; they are plant hairs. Gorse, the prickly bush so common on heathlands, conspicuous by its bright yellow flowers, possesses both leaf and stem spines.

Cactus spines are outgrowths of the skin of the plant. The thorns or emergences of bramble are climbing devices.

In desert plants the midribs of leaves may become adapted as thorns. Skin outgrowths and branches may also form prickles.

Hawthorn spines are really dwarf branches given off from main stems. The spines may support leaves.

The dog rose scrambles over other vegetation using its backward-pointing thorns or emergences. High above the ground the flowers are well displayed to pollinating insects. Ripened fruit is also prominent; this encourages seed dispersal by birds.

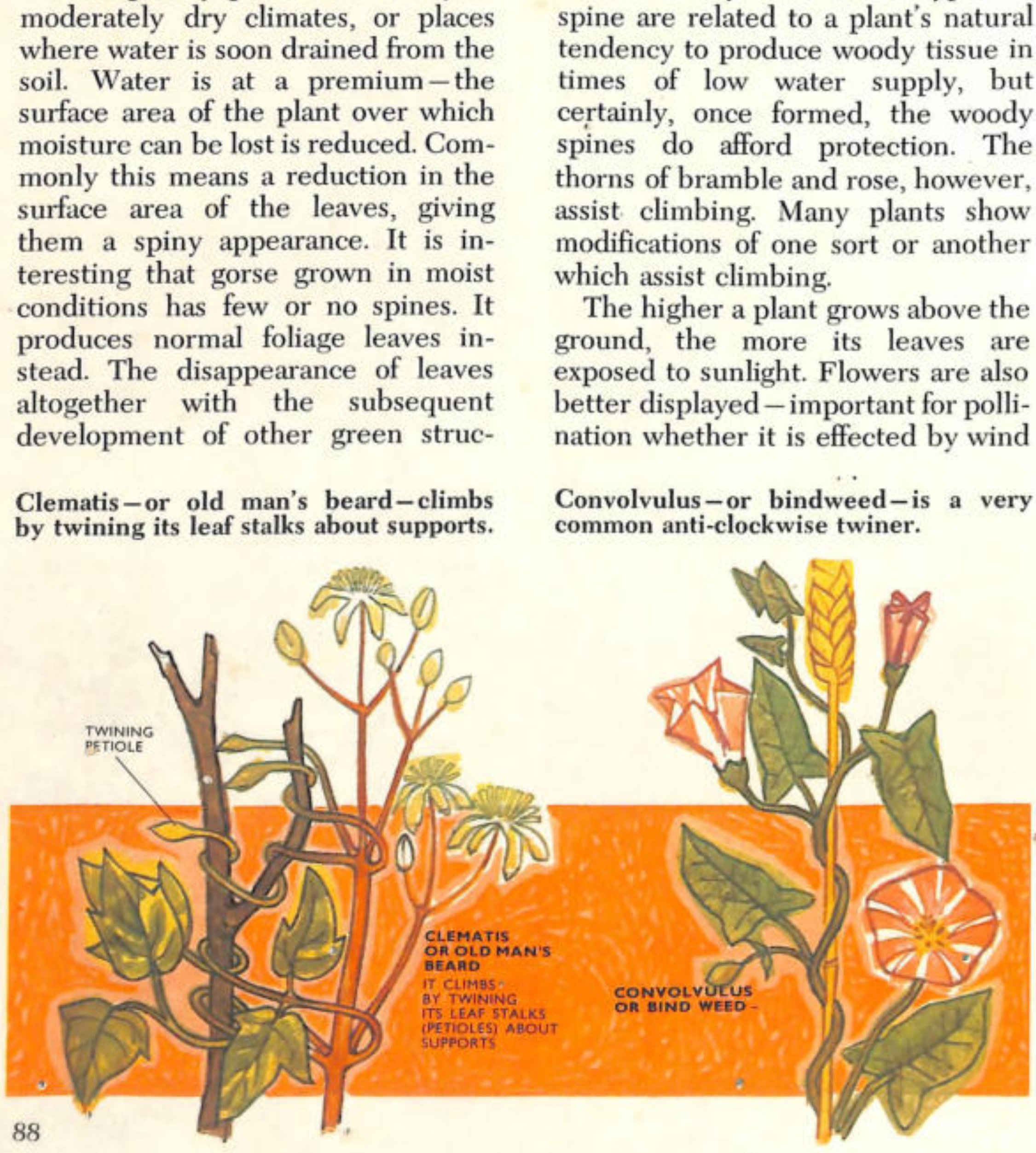
Most prickly plants live in dry or moderately dry climates, or places where water is soon drained from the soil. Water is at a premium – the surface area of the plant over which moisture can be lost is reduced. Commonly this means a reduction in the surface area of the leaves, giving them a spiny appearance. It is interesting that gorse grown in moist conditions has few or no spines. It produces normal foliage leaves instead. The disappearance of leaves altogether with the subsequent development of other green structures for food-making is also an advantage in dry conditions. Such structures, usually possessing far more mechanical tissue than leaves, are not so likely to shrink on drying.

It is likely that other types of spine are related to a plant's natural tendency to produce woody tissue in times of low water supply, but certainly, once formed, the woody spines do afford protection. The thorns of bramble and rose, however, assist climbing. Many plants show modifications of one sort or another which assist climbing.

The higher a plant grows above the ground, the more its leaves are exposed to sunlight. Flowers are also better displayed – important for pollination whether it is effected by wind

Clematis – or old man's beard – climbs by twining its leaf stalks about supports.

Convolvulus – or bindweed – is a very common anti-clockwise twiner.



In Virginia creeper the climbing aids – tendrils – are probably formed from terminations of the main stem.

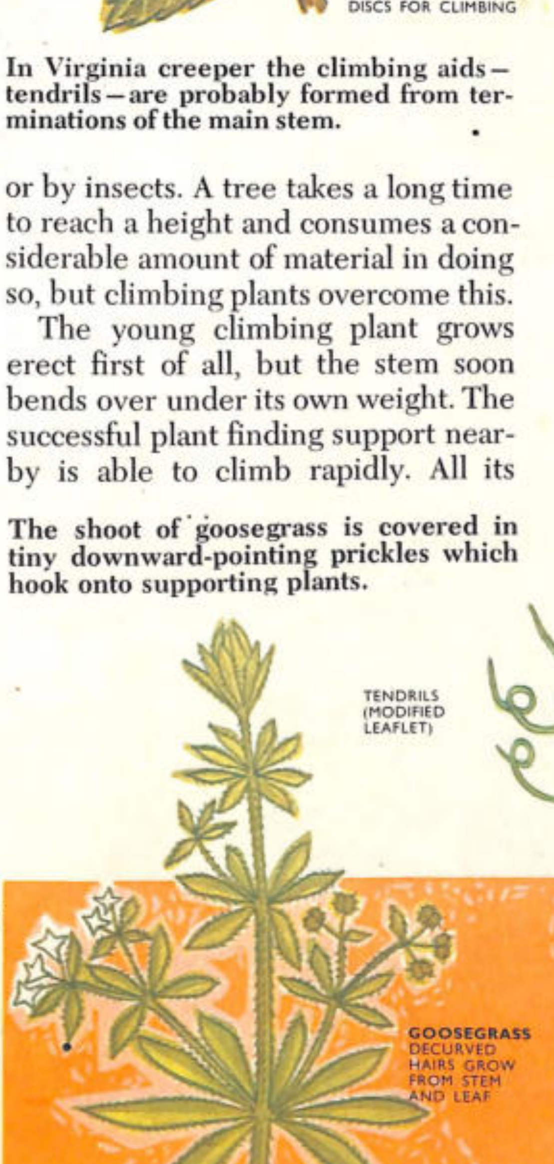
The honeysuckle is a common clockwise twiner that naturally grows in hedges and thickets where abundant support is available.

or by insects. A tree takes a long time to reach a height and consumes a considerable amount of material in doing so, but climbing plants overcome this.

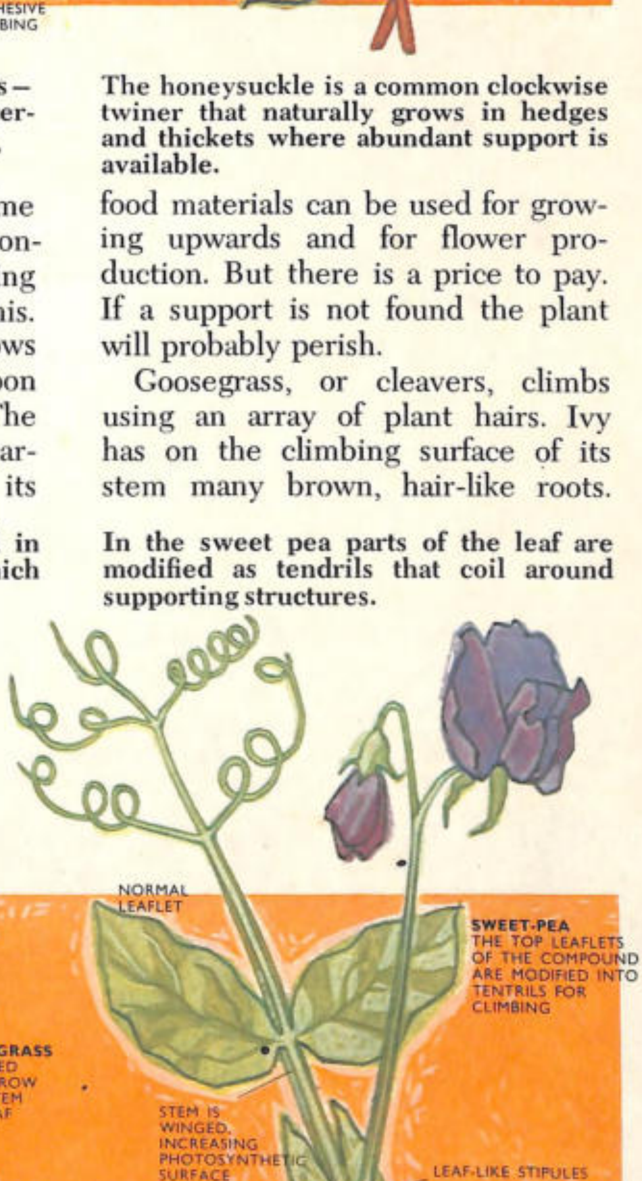
The young climbing plant grows erect first of all, but the stem soon bends over under its own weight. The successful plant finding support nearby is able to climb rapidly. All its food materials can be used for growing upwards and for flower production. But there is a price to pay. If a support is not found the plant will probably perish.

Goosegrass, or cleavers, climbs using an array of plant hairs. Ivy has on the climbing surface of its stem many brown, hair-like roots.

The shoot of goosegrass is covered in tiny downward-pointing prickles which hook onto supporting plants.



In the sweet pea parts of the leaf are modified as tendrils that coil around supporting structures.



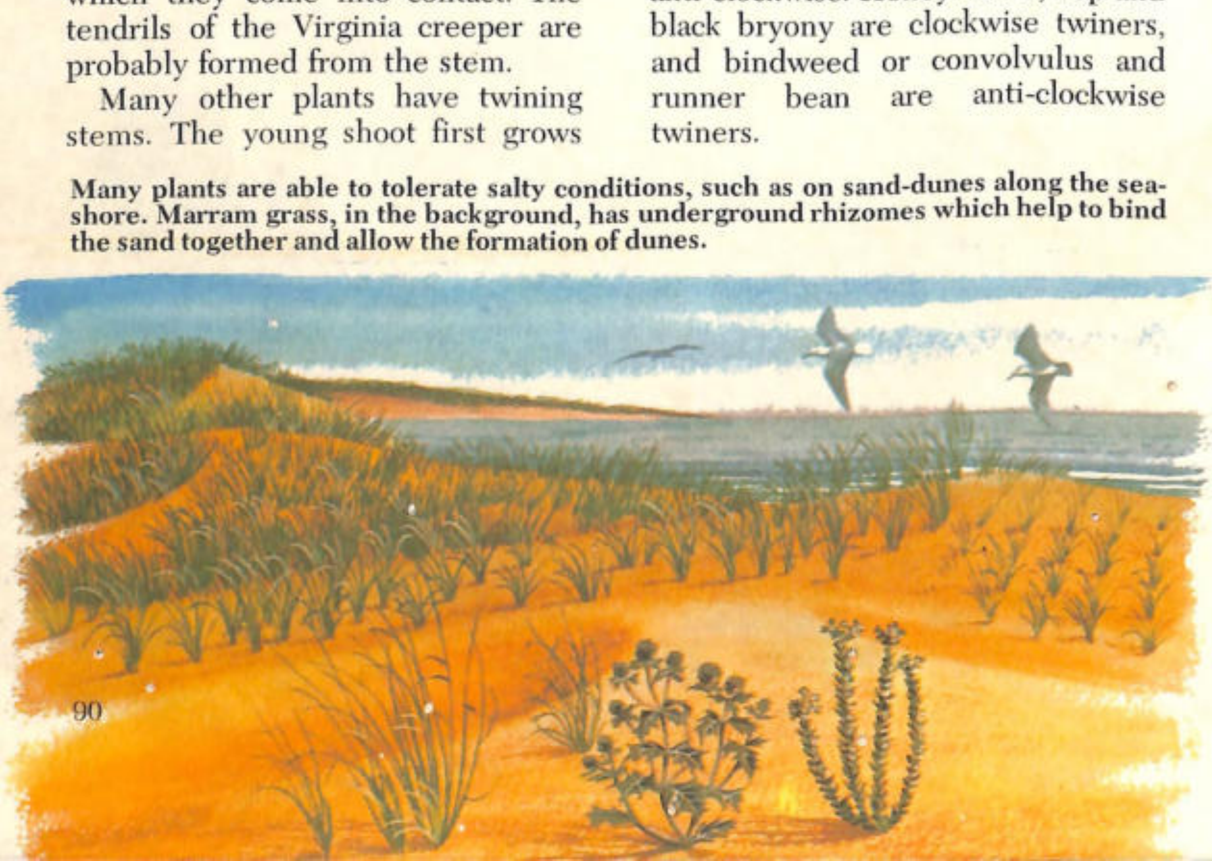
Ivy, a common climber of both trees and walls, has aerial roots on the underside of its stems. Above the climbing region the leaves are regular in shape, there are no aerial roots and flowers are supported.

These produce a fluid that glues them to the surface up which they are climbing. In the sweet pea parts of the leaf are modified as tendrils which twine around objects with which they come into contact. The tendrils of the Virginia creeper are probably formed from the stem.

Many other plants have twining stems. The young shoot first grows erect but soon bends over and the tip swings round in circles, which helps to locate a support. In Britain honeysuckle encircles trees.

Climbers may twine clockwise or anti-clockwise. Honeysuckle, hop and black bryony are clockwise twiners, and bindweed or convolvulus and runner bean are anti-clockwise twiners.

Many plants are able to tolerate salty conditions, such as on sand-dunes along the sea-shore. Marram grass, in the background, has underground rhizomes which help to bind the sand together and allow the formation of dunes.



CHAPTER 8

Camouflage and mimicry

THE great competition between the many different kinds of living animal has led to every conceivable form of defence and attack. Speed, armour plating, warning coloration and foul smell are often used as a means of survival. Some of the most interesting and remarkable adaptations, however, are those concerning camouflage and mimicry.

Camouflage involves the resemblance of the animal to its surroundings so that it is inconspicuous to its predators and, indeed, to its prey. Some of the best examples are to be found among insects. Many butterflies, although they may be brightly coloured on the upper side, resemble leaves when at rest. Stick insects and leaf insects are other well-known examples. Several species of thorn hopper are almost indistinguishable from thorns when sitting on twigs, and various caterpillars resemble twigs themselves.

Not all animals have colour vision. Apes and monkeys have as wide a range as Man himself, but most other mammals are believed to see only black and white and various shades of grey. The bullfighter's cape would work equally well if it were blue or green, for it is the movement that enrages the animal and not the colour

(left) The young of antelopes and deer have markings that help to conceal them from predators during the first few weeks of their life. (centre) The bittern adopts this curious position to avoid detection when danger threatens. (right) The chameleon is a master of camouflage, able to change its colour to blend with that of the surroundings and so conceal itself from prey and predators.

(1) A cossid moth that mimics a flower. (2) A blemish leaf grass-hopper, a leaf mimic. (3) A large emerald moth whose colouring matches perfectly with its surroundings when at rest. (4) A lichen beetle that mimics lichens on the bark of trees. (5) A pine beauty moth caterpillar. (6) A giant stick insect from South America. (7) Various kinds of thorn tree hoppers. (8) Treble bar moth that has lines on its wings to match the patterns of the bark. (9) A purple thorn moth caterpillar.

of the cape. Birds, many insects and fishes see colours, and it is significant that these animals are frequently brightly coloured. On the other hand it must not be assumed that a creature (or its enemies) has colour vision just because it is strikingly coloured. The stripes of the zebra are probably effective as a black and white pattern. Even so, whether they have good colour vision or not, colour plays a big part in the life of animals.

Colour may be used for concealment, as a warning or for display purposes. One way to remain concealed from prey or from enemies is to merge with the colour of the surroundings. Stick insects, leaf insects, thorn hoppers, and various caterpillars have been mentioned. The mainly brown grazing animals such as antelopes merge with the plains where they feed, especially effective colouring when one remembers that the lions and other predators see only in shades of grey. This general colour resemblance is only part of the answer, however. A solid body will tend to stand out in relief against the background through shading effects. A great many animals have darker colours on the top surface than underneath, a feature called countershading. Sunlight usually comes from above so that there is shadow below. This effect is countered by the coloration of the body and the result is that all shadows disappear and the animal merges as a flat shape into the background. Countershading is common among the grazing animals and also among fishes that swim near the surface of the sea. A mackerel, for example, has a dark back and a silvery underside.

Many frogs are green in colour and blend very well with the vegetation amongst which they live.

Many animals have what on plain surfaces appear to be prominent patterning, but on being placed in their natural surroundings the patterns no longer appear prominent but break up the outline of the animal's body and draw attention away from the whole shape. Fishes, snakes and many ground-nesting birds make use of this type of coloration.

Numerous animals, especially insects, that are poisonous or distasteful, are brightly coloured. Wasps and cinnabar moths and caterpillars are good examples. It is thought that the bold yellow or red and black pattern will quickly be learnt by birds and other predators and will be associated with unpleasant taste. The insects will then be left alone. In fact, many harmless insects gain protection by mimicking the poisonous ones.

Colour for display purposes is used particularly by birds, whose sense of colour vision is good, of course. The male of the species is usually more brightly coloured than the female and uses his brightly coloured feathers to attract a mate. An outstanding example of this is the peacock which erects its tail feathers in a huge fan to attract the female. Colours also trigger off other actions such as feeding. Some young birds open their beaks to be fed when they see the shape or the colour of the parent's head. The inside of a young bird's mouth is also often brightly coloured, too, which encourages the parent birds to supply food.

Many animals escape enemies or conceal themselves from prey by changing their colour to match that of their background. The chameleon is the famous example usually quoted, but its powers of changing colour are surpassed by many other animals including many fishes, octopuses and squids, and some frogs.

The pigment that gives the animals their colour is usually contained in special cells called chromatophores. Colour change is usually brought about by redistribution of the pigment. The size of the cells may be altered by nerves or hormones (chemical messengers) in response to light falling on and around the animal or the pigment itself may be concentrated or dispersed. As the cells expand, more colour appears and

The red grouse has plumage whose colour suits it to its marshy heathland home. The lower part of the illustration shows the concealing or cryptic markings of a golden plover chick and its egg which looks much like a pebble.

Many of the creatures of the rain forest have markings that blend with the dappled lighting of their surroundings.

the skin becomes darker, while it becomes lighter when they contract.

A chameleon is able to change colour relatively slowly but some fishes, such as the flounder, are able to match their surroundings very quickly. A flounder will even alter its colour to match the squares of a chequered board. Its colour-changing ability is under the control of nerves. Such good control is not possible with hormones. In frogs for example the whole animal either becomes dark or light. One part cannot stay light while the other changes to dark.

The most rapid colour changes are shown by the cuttlefish and its relatives the octopuses and squids. The pigments are of three colours – red, yellow and black – enclosed in tiny cells. Each colour cell has its own muscles which, when stimulated, cause the cell itself to expand or contract. The muscles operate as a result of nerve signals from the brain.

Many animals imitate or mimic others in shape and colour or closely resemble plants or parts of plants. In this way they may be concealed from their enemies or when they re-

The disruptive pattern of the left-hand snake distracts from the whole shape which would be more obvious were the snake of a single colour (right).

The chameleon is noted for its ability to change colour and merge with different backgrounds, but it is only one of many animals to do this for protection. Colour change is usually brought about by the redistribution of pigment. The latter is contained in special cells called chromatophores. The size of these or the distribution of pigment within them is altered by the action of nerves or hormones as a result of light in the animal's surroundings. As the cells expand, or as the pigment expands, more colour appears. The skin becomes lighter when the cells or the pigment itself contracts.

semble poisonous creatures they gain protection through being avoided. The creature whose colouring etc. is copied is called the model, and the imitator is known as the mimic. In some parts of Africa and Madagascar, the male and female swallowtail butterfly are alike, but through most of Africa the female mimics a distasteful butterfly, *Danais*. Another example is the clearwing moth which is protected by its resemblance to the hornet.

Many flatfish have quite remarkable powers of changing colour and will do their best to match even a chequered board as a background.

There are two basic kinds of mimicry. In the first a distasteful animal is mimicked by a harmless one, and, in the second, one distasteful animal mimics another. Through this latter kind of imitation the risk of either animal being eaten is lessened as it is spread between them.

There are many ant and spider mimics. The caterpillar of a South American moth is remarkable in its mimicry of a spider. Birds tend to leave the caterpillar alone, deceived into thinking that it is a distasteful spider. A Malayan spider has the cunning habit of spinning a small web (in the centre of which it sits) which looks just like the droppings of birds. Butterflies which normally visit bird droppings may be lured into the waiting jaws of the spider.

The young of one kind of South American grasshopper are so ant-like that even an experienced studier of insects can be deceived until he examines them closely. Nearly every spider group has its ant mimics. Not only do these spiders look like ants, they also have similar habits.

CHAPTER 9

Defence and attack

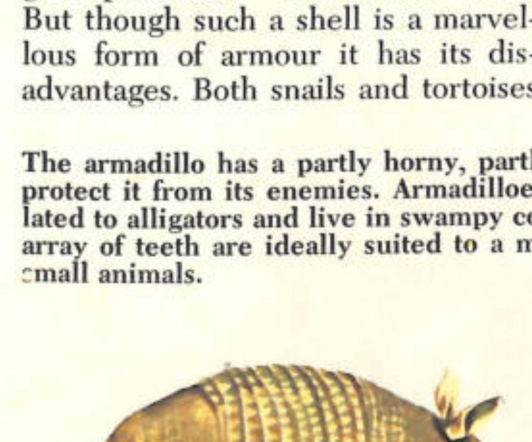
SOME of the devices that animals employ in defence or attack have been outlined in the previous chapter, particularly those concerned with colour and camouflage. Colour is perhaps of prime importance even when an animal has a hard protective cover. The patterning is often such that the animal is concealed from the view of an enemy.

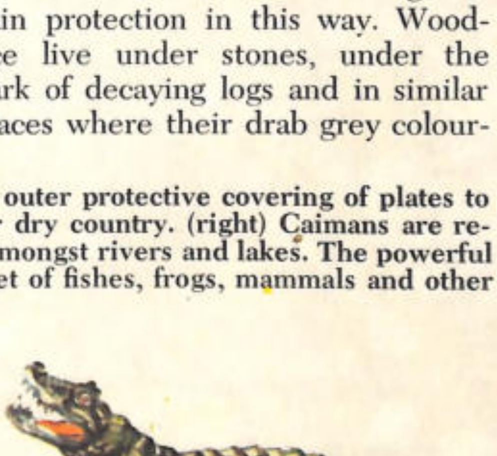
Many creatures are protected within horny or bony outer coverings. Snails are able to withdraw their soft, fleshy bodies within their limy shell both as a protection against enemies and to prevent themselves from drying up in hot weather. With their long tentacles outstretched they are able to detect anything unpleasant in their surroundings.

Tortoises, like snails, are able to gain protection within their shell. But though such a shell is a marvellous form of armour it has its disadvantages. Both snails and tortoises are such slow-moving creatures because they have to carry their 'homes' around with them that they are easy victims to natural enemies, such as fire and floods. Even so, tortoises have been able to survive as a group almost unchanged for millions of years and this must be due mainly to their most effective armour.

In snails and tortoises the shell is usually in one piece. But many animals have a shell of many parts, and these are moveable, just like the separate pieces of a suit of armour. Woodlice, armadilloes and pangolins are examples. These animals are able to roll themselves into a ball when danger threatens. The pill millipede, which closely resembles a woodlouse, is able to do the same thing. All gain protection in this way. Woodlice live under stones, under the bark of decaying logs and in similar places where their drab grey colour-

The armadillo has a partly horny, partly bony outer protective covering of plates to protect it from its enemies. Armadilloes prefer dry country. (right) Caimans are related to alligators and live in swampy country amongst rivers and lakes. The powerful array of teeth are ideally suited to a mixed diet of fishes, frogs, mammals and other small animals.





ing helps to protect them from enemies.

Hedgehogs have a thorny covering of spines. When attacked by a predator they roll into a ball and present this formidable barrier to their opponent. Porcupines too have an effective defensive array of long spines. These can be erected by the action of very powerful muscles in the skin. A porcupine moving about at night has the odd habit of rustling its spines by rubbing one against the other and producing a very loud sound. This probably serves a similar function to the rattle of a rattlesnake warning other creatures of its presence.

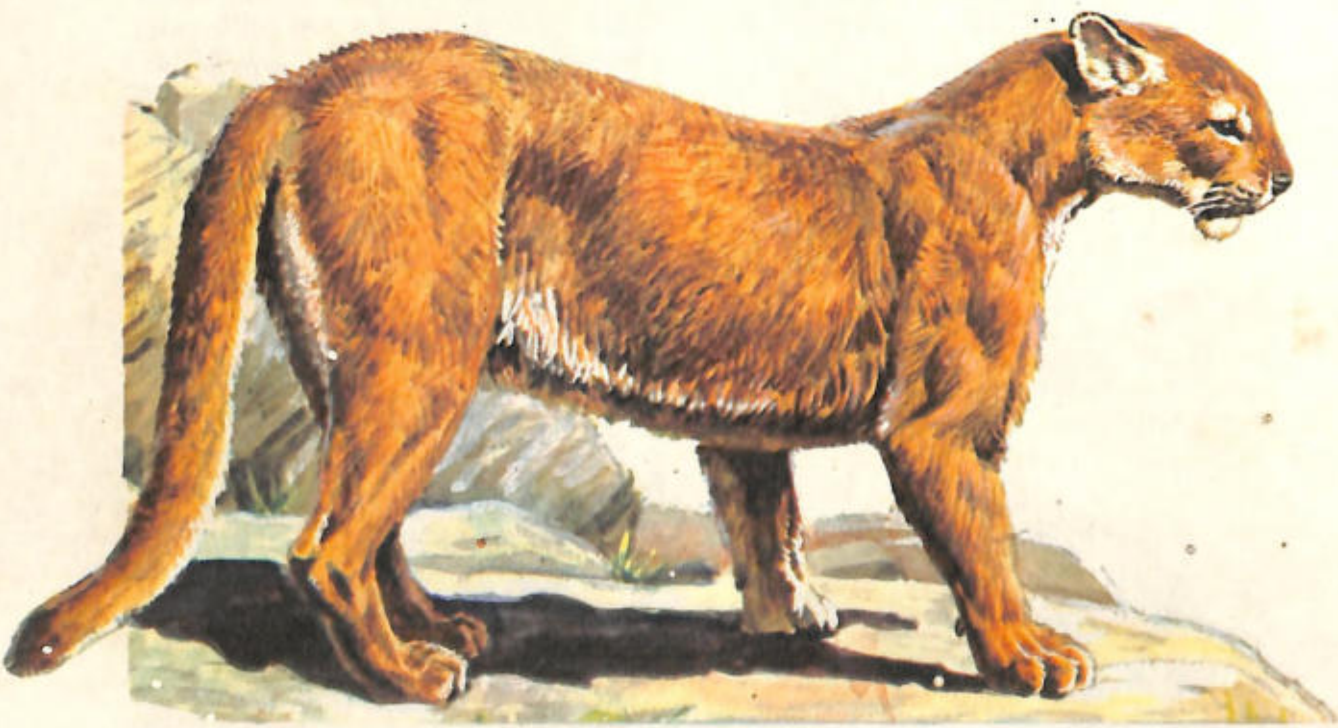
Many kinds of fishes have spines. The porcupine fishes and puffers are examples. They are able to inflate themselves like football bladders to scare off would-be attackers.

Some fishes have poisonous spines or poisonous flesh and are often brightly coloured, presumably as a warning to other creatures to keep their distance and as a warning that their flesh is unpalatable.

Many other distasteful creatures are brightly coloured. The adults and caterpillars of the cinnabar moth are examples of distasteful insects that have vivid coloration.

The use of evil-smelling fluids and of poisons is commonplace in the animal kingdom. Many adult and young insects resort to the former method of defence. Many bugs, for example, and beetles have special glands which release repugnant fluids. Amongst mammals, skunks are notorious for this practice. They are able to release a spray of fluid several feet. Certain species of snakes are known to spit out fluid which can

The cougar (also known as the puma or mountain lion) lives in the mountainous areas of western North America and most mountainous parts of South America. They hunt largely at night, living on deer, sheep and similar mammals.



temporarily injure the eyes of any adversary.

Snakes are probably the best known creatures for producing poison. Many use poison for killing their prey. Poisonous snakes have fangs, which are hollow teeth specially modified for injecting poison produced by poison glands. In some the fangs are fixed, but in others they are moveable. The venom is saliva that is modified. The prey is therefore part digested before it is consumed.

The pit vipers are snakes with an extraordinary mechanism for detecting prey. The pits contain heat sensitive organs that are so sensitive as to be able to detect the warmth of a mammal's body several feet away (see page 108).

But snakes are not the vicious creatures that popular stories would have us believe. Most do not attack for the sake of it. In fact, many have developed the art of bluffing to a fine degree. It may even be better developed than the art of fighting. The cobras and the rattlesnakes are excellent examples of this, and the cobras in particular are noted for the alarming effect that they produce by raising the ribs of the neck region which 'spreads the neck out' to form a hood. Some snakes even act as if they were going to bite when, in fact, they keep their mouth closed. Many snakes are able to inflate their bodies as the cobra inflates its hood. They appear to be much larger than they really are and so frighten an enemy. A number of snakes also display bright warning colours when they are sufficiently disturbed.

The porcupine has very long quills, which it can erect with powerful skin muscles, as a deterrent to would-be attackers.

Insects often have well developed powers of stinging. All female insects possess some form of egg-laying equipment at the hind end. In many cases these organs are very tiny and completely hidden within the body. They simply form a channel for the eggs passing out of the body. They are used to place eggs in a suitable place. For this reason they are called ovipositors or egg-placers.

The larva of the eyed hawk moth normally hangs upside down and shading effects partly conceal it. If put the other way up (top) it stands out in relief.

The cinnabar moth and its caterpillar are both unpleasant to taste and are brightly coloured to warn predators.

Polar bears have enormously strong front legs and are able to kill the seals which form the main part of their diet with a single blow of the front paw. They also feed on crabs, fishes, molluscs and small mammals such as lemmings.

Many grasshoppers possess curved egg-placers, while some ichneumon flies – parasites that lay their eggs inside the young of other insects – have very long, fine egg-placing tubes. These are frequently mistaken for stings.

However, in many bees, wasps and ants, the egg-laying apparatus is actually modified as a sting and does not appear to be used in egg-laying at all. It is a weapon of defence and among the wasps it is used for paralysing grubs, spiders and the like that are used as food for the larvae. Obviously only females (that is, queens and workers) can sting, for the males (drones) have no such apparatus.

Snails are able to withdraw their soft bodies completely within their coiled, limy shells. Even so, birds such as thrushes are able to break them open on their 'anvils'—stones that they use to fling the snails against.

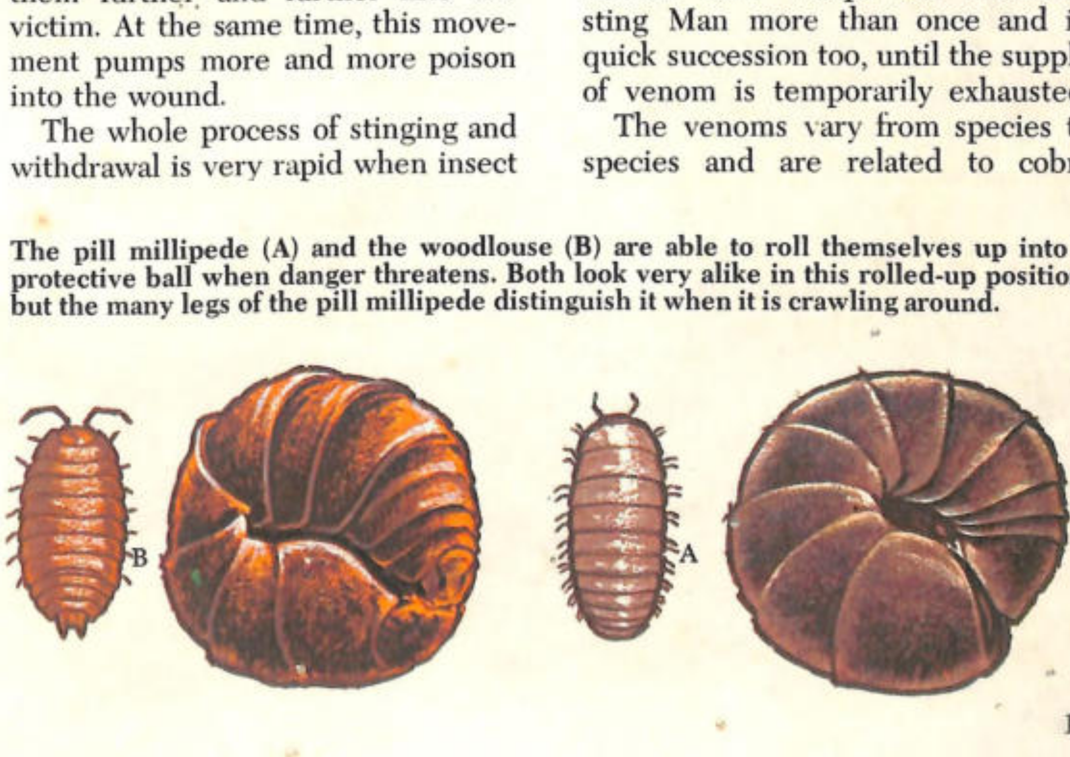
The honey-bee's sting is a complicated structure that normally rests in a cavity at the hind end of the body. There are three parts to the shaft of the sting and they fit together to form a tube. A single stylet partly sheathes two lancets. When stinging, the body is arched so that the sting is extended at right angles to the enemy. The point of the shaft penetrates the enemy and the two lancets move alternately to and fro. The ends of the lancets are barbed, and the movement pulls them further and further into the victim. At the same time, this movement pumps more and more poison into the wound.

The whole process of stinging and withdrawal is very rapid when insect fights insect. But when stinging an enemy with tougher skin, such as Man, the barbs on the sting prevent its withdrawal. The bee can then pull herself free only by leaving the sting behind. In doing so she leaves the poison gland and other organs and is fatally wounded. A bee sting should be scraped from the skin, not pinched out, for any pressure on the poison sac will only drive out more venom into the wound.

Wasp stings have only tiny barbs and can be withdrawn easily from human skin. Wasps can therefore sting Man more than once and in quick succession too, until the supply of venom is temporarily exhausted.

The venoms vary from species to species and are related to cobra

The pill millipede (A) and the woodlouse (B) are able to roll themselves up into a protective ball when danger threatens. Both look very alike in this rolled-up position, but the many legs of the pill millipede distinguish it when it is crawling around.



The cobras are able to put on bluffing antics by raising the ribs of the neck region so that the hood and its markings are very prominent. It will usually do this to frighten away an enemy rather than attack it.

venom. They are rapidly fatal to other insects but rarely more than a nuisance to Man because of the small amount injected.

Insects that live in colonies work together to protect their nests. Ants are able to detect the smell of strangers in their midst and soldiers may attack an intruder viciously before casting it out of the nest. Worker wasps and bees will similarly work together to expel strangers.

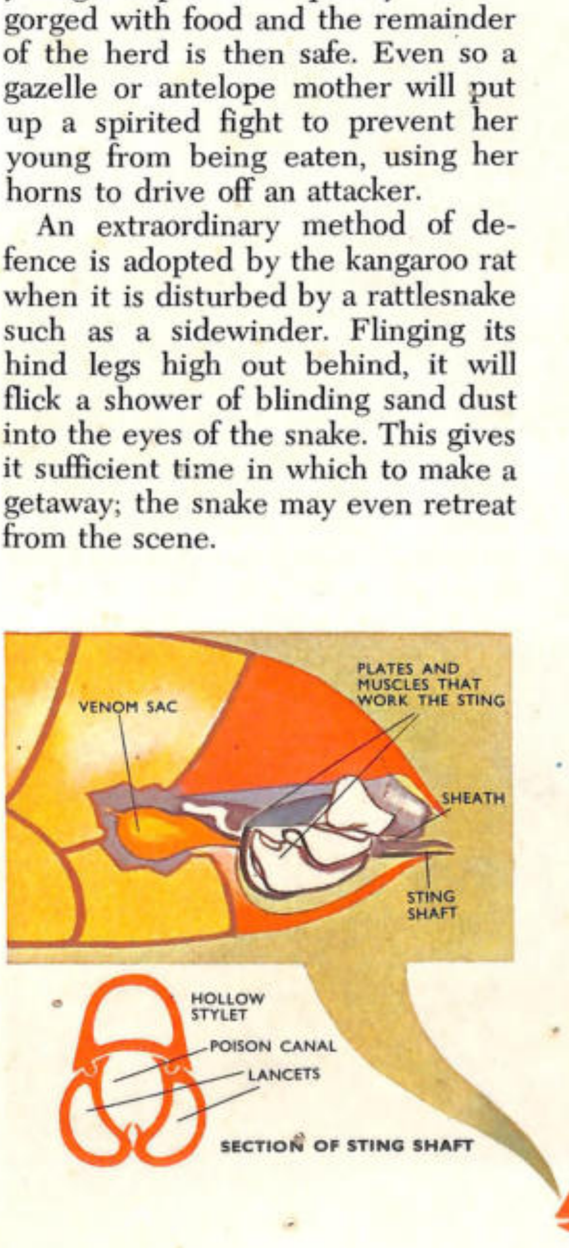
An equivalent amongst mammals is the banding together of great herds of grazing animals such as zebra, wildebeest and many of the antelopes. This action helps to protect them from the predatory activities of the big cats, such as leopards, lions and cheetahs. It is quite extraordinary to see a herd of zebra wait patiently near a waterhole only a short distance away from a group of lions drinking. It is almost as though they know when the lions are hungry and so will be on the lookout for animals that stray from the herd. Usually the female lion does the hunting for her mate and the rest of the group containing youngsters. Often two or three lions will work together to make a kill, moving in on a stray animal from several sides and then running the animal to earth after a relatively short chase. It is on their great migrations across the African plains that the predators take their greatest toll of the antelope and zebra herds, for it is at this time that the mothers give birth to their young. Hyaenas and others that are normally thought of as scavengers will then kill the young almost as they are born in some instances. But because the herds produce so many

The cormorant is an expert underwater swimmer and catches fish in its beautifully adapted beak.

The sting of the honey bee is barbed. When it tries to free itself after stinging a human the sting apparatus including its muscles and the poison sac are torn from the bee's body and the bee will consequently die.

young the predators quickly become gorged with food and the remainder of the herd is then safe. Even so a gazelle or antelope mother will put up a spirited fight to prevent her young from being eaten, using her horns to drive off an attacker.

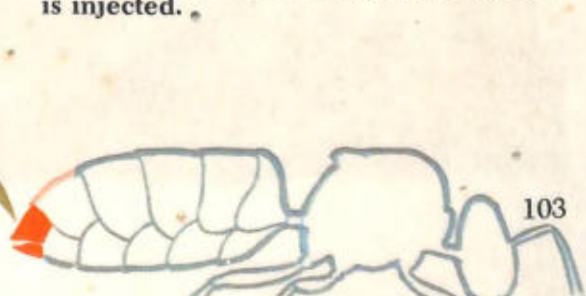
An extraordinary method of defence is adopted by the kangaroo rat when it is disturbed by a rattlesnake such as a sidewinder. Flinging its hind legs high out behind, it will flick a shower of blinding sand dust into the eyes of the snake. This gives it sufficient time in which to make a getaway; the snake may even retreat from the scene.

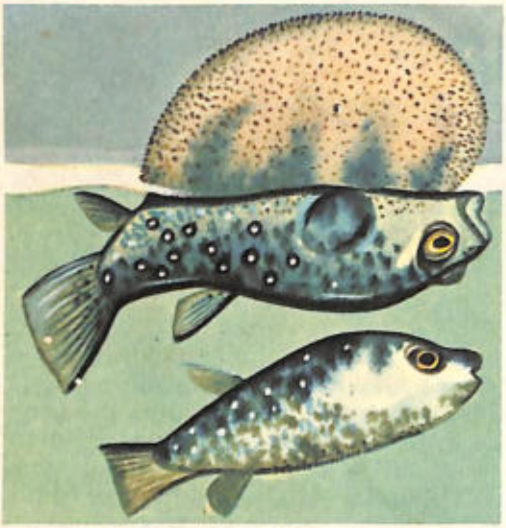


The wonderful development of the feet and beaks of birds for various purposes has been dealt with in an earlier chapter, but there are still a number of other features of bird life associated with defence and attack. The eyes of hunting birds, for example, are extraordinarily well developed as is the hearing of a bird such as an owl which hunts at dusk. An owl's eyes are at the front of its head as are our own and this enables them to judge distances very accurately—of great importance in judging the exact distance and position of their prey. Owls also have excellent vision in twilight conditions.

Hawks have a very wide range of vision, more than one hundred and eighty degrees, and an owl can turn its head almost in a complete circle. The hovering flights of the kestrel

(left) A honeybee cutaway to show diagrammatically the sting apparatus and the various plates and muscles that move the lancets. Below it is a cross-section of the shaft, showing the hollow stylet, the lancets and the canal along which poison is injected.





The globe fishes or puffers are so named because of their habit of swallowing air or water when they become inflated like a football bladder. The alarming appearance may scare off enemies.

The Arctic hare lives in the tundra regions of Canada and Greenland. Over most of its range it is white the whole year through so that it blends with its snowy surroundings. The southerly forms have a greyish back which turns to white during winter.

can only be wondered at as it effortlessly maintains its position above an unwary prey before diving onto it from above.

Birds such as terns will band together in order to drive off marauders such as skuas, who eat their eggs and young. Many birds will also try to entice a predator away from their nest by means of bluffing, flying away from the nest, in the hope that the predator will try to attack them or will think that the nest is elsewhere.

Many insects copy or mimic others in colour or in habits so that they gain protection. Here some leaf-like bugs are shown in the company of parasol ants when the ants go on their leaf-hunting sorties.

Many of the large African grazing animals go about in herds to reduce the risk of attack from the large predators such as lions. The zebras seem to know when they are safe from attack and patiently await their turn at the water-hole.

CHAPTER 10

The night life of animals

NIGHT comes and a great changeover takes place in the animal world. The creatures of the day seek their resting places. A new population wakes and emerges. Man retires indoors at twilight and usually remains unaware of the shifting pattern of life outside. Few creatures stick rigidly to a routine of sleeping in the daytime and awaking at night, however. Even the fox, which is regarded as a nocturnal animal, can often be seen taking a stroll in the daylight. Nevertheless, there are a number of animals which are frequently to be found wandering in search of food at dusk or in darkness.

The night creatures spend their active lives in very poor light. When the sun has set the only light comes from the stars or the moon. In response to this limitation eyes have become specialised to react to small quantities of light. Other sense organs, notably smell, hearing and touch, have become acute.

But night may be beneficial. It is cooler and so the dampness of the air is greater. Many backboneless creatures have little or no protection against drying up during the day and so they emerge only after sunset. Examples are earthworms, snails, slugs and woodlice. In deserts, where water is always scarce, nearly all animals appear only during the cooler more humid night. The intense heat of the day is avoided by burrowing beneath the ground.

Owls have whisker-like feathers that are very sensitive to touch. The flight feathers have delicate filaments at their edges to ensure silent flight.

The aye aye has long fingers and toes with claws. The long third finger of each hand is used to get the pith out of trees and also to collect wood-boring insects.

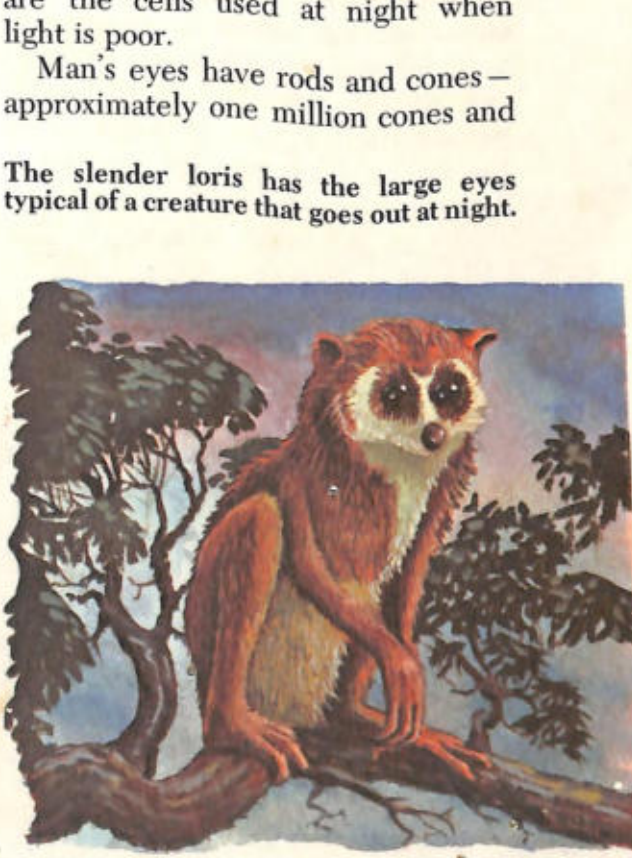
The star-nosed mole is a burrowing creature that lives in the north-eastern United States and south-east Canada. It has a star-shaped growth on its nose.

The light sensitive tissue at the back of the eye – the retina – is found inside the back of the eyeball. Light rays are concentrated onto it by a lens. The light sensitive cells in the retina are of two basic types, rods and cones. Cones are the least sensitive to light and come into use only when light is good. In Man and a few other mammals they are responsible for colour vision. The rods are much more sensitive to light. They are the cells used at night when light is poor.

Man's eyes have rods and cones – approximately one million cones and

The nightjars are nocturnal birds with long stiff bristles around the base of the beak.

The slender loris has the large eyes typical of a creature that goes out at night.



one hundred million rods. He is able to see in bright light and in dim light, at night. But at night he only sees in greys and silvers for the rods cannot detect colour. More specialised night creatures have only a few cones in their eyes and some bats have none at all.

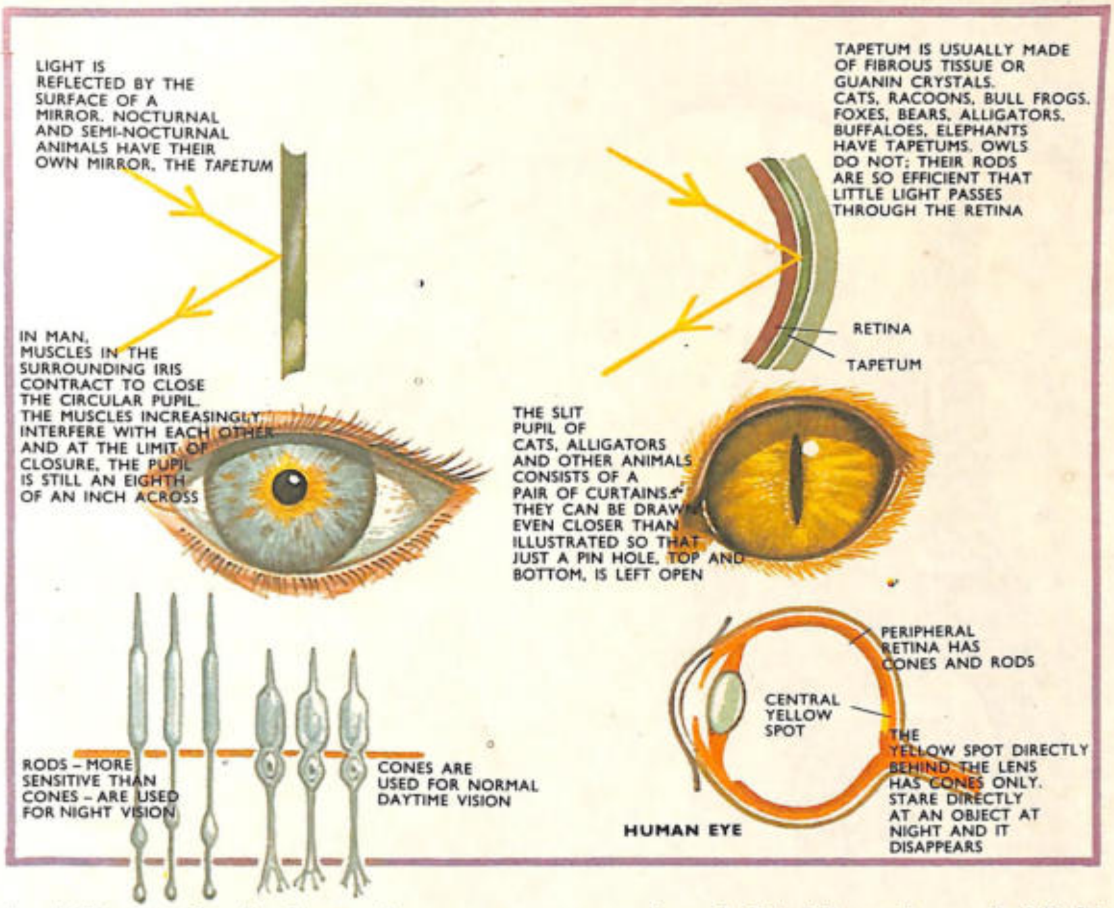
Another property that makes Man's eyes good for seeing at night is the large diameter of the eyeball so enabling a large quantity of light to be received. Cats, foxes and other night creatures have large eyeballs. The owl's eyeballs are so expanded that they cannot swivel in their sockets. Instead this night hunter has to move its whole head if it wishes to see in a different direction. Horses, bears, lions, deer and buffaloes have large eyes and have good day and night vision.

A spectacular adaptation to the night vision of some hunting creatures is an internal mirror or tapetum at the back of the eye. If any of the light passing through the retina fails to be absorbed, it can be reflected by the mirror back through the retina. Everyone has noticed how cats' eyes glitter in the light of a torch. The glitter is really the torchlight reflected back through the pupil by the mirror.

Sensitivity to light is just one way in which an animal can learn about its surroundings. Other sense organs also convey information and at night when illumination is poor they are of particular value. In fact, some night creatures have little use for their eyes at all.

The hairs of mammals and the feathers of birds not only provide insulating layers against the cold but each is also provided with a tiny nerve fibre so that if it comes into contact with some object, immediately the animal is aware of the interference. Particularly sensitive to touch are the large bristles or vibrissae extending from the sides of an animal's face. Many night venturing mammals, whether they have good night vision or not, have very well developed vibrissae and also have extended hairs from their eyebrows. Passing through dark holes and tunnels the bristles touch the sides and inform the creatures as to the dimensions of the space they are passing through. If the bristles touch another

Pit vipers have two sensory pits, one on each side of the head, between eye and nostril. The pits are so sensitive to temperature that warm-blooded prey can be detected.

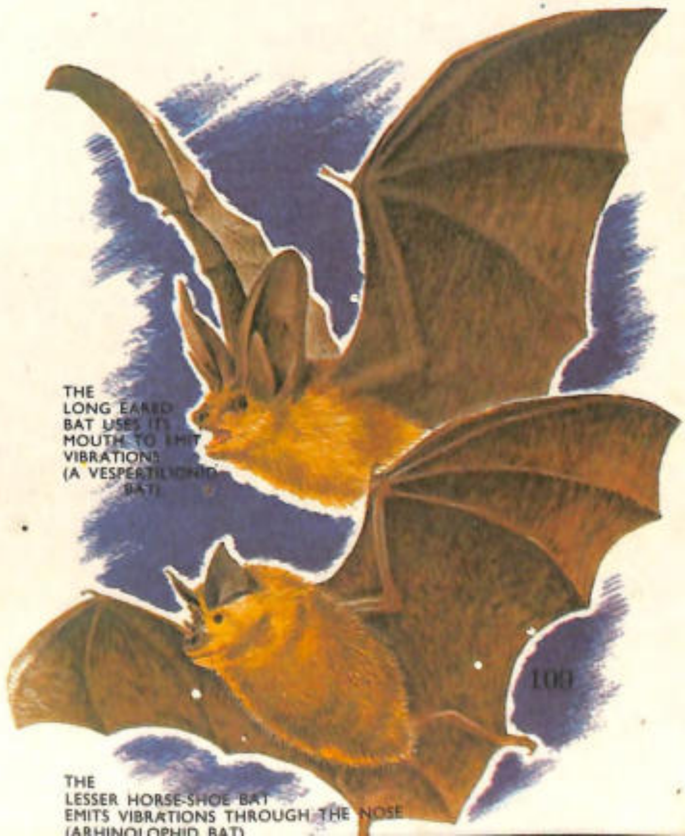


(top) Nocturnal animals may have a tapetum or mirror behind the retina so that light not first absorbed is reflected back again. (middle) The iris of Man is circular and there is a limit to the size that it can reduce to. Animals with very sensitive retinas prevent excessive light from entering the eye by a more efficient slit iris. (bottom) Man's rods are collected around the periphery of the eye. Directly behind the lens is a small area with cones only. Consequently Man sees best at night by staring to one side of an object.

animal then they trigger off a violent reflex action. A cat will snap out its paw in anticipation of its victim; a mouse will flee for its life.

Certain feathers covering the faces of nocturnal birds are similarly specialised. The owl is well equipped with them and so is the nightjar.

The sense of smell is also independent of light, and the humid atmosphere at night is very suitable for carrying smells. Small creatures such as shrews and field mice are particularly reliant upon their noses for providing information about their



Bats navigate at night by emitting rapid, high-pitched squeaks and picking up the echoes with their enormous ears.

Fruit-eating bats occur in quite incredible numbers in certain parts of the tropics. They migrate considerable distances every evening at dusk to feed off fruit and nectar.

surroundings. Their eyeballs are correspondingly small and inefficient for night vision. They search for berries and insects largely by scent and touch.

Night-flying moths are partly attracted to flowers by their odour. The scent is detected by their sensitive antennae, which are equipped with special cells.

Hearing is the other important sense and it may be acute in night animals. Each animal may communicate with its fellows, however, without giving itself away, for different creatures have their own 'channel' of sound waves. The vibrations of the air that they create with their tongues and mouths are only detectable by carefully attuned ear drums of their own species. The night—though silent to Man—may be filled with noises that he cannot perceive.

Perhaps the most remarkable of all adaptations is the system that bats use to avoid obstacles and to detect prey. They use their own sounds as a navigating device. The high-pitched squeaks are emitted from the mouth or nose at frequent intervals. The sounds bounce back from surrounding objects and these echoes are detected by the bats' trumpet-like ears. The rapidity and strength of the echoes provide bats with a detailed account of their surroundings.

CHAPTER 11

Animals that hibernate

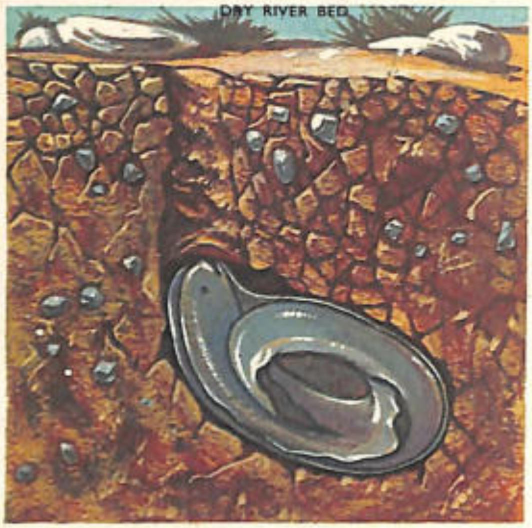
In cold and temperate regions many animals disappear at the beginning of winter. They may do so because they cannot withstand the cold, or because they are unable to obtain food during the cold season. Many birds migrate to warmer lands, but among other animals hibernation is common. This is a state of inactivity or deep sleep during which the body workings slow down almost to a stop. The body temperature, even in mammals, falls to within a degree or two of that of the immediate surroundings.

Many simple, single-celled creatures are able to overwinter at the bottom of a pond as tiny cysts. With the onset of cold weather a hard, protective wall forms around each of them and they are able to survive within it until warmer weather arrives in spring. Snails, insects, frogs and reptiles are cold-blooded animals that hibernate.

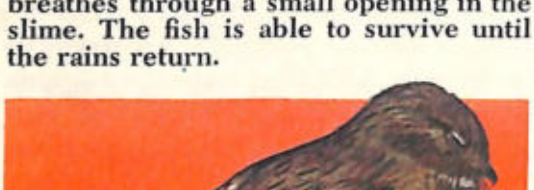
True hibernation is not known among birds, though the body temperature of an American nightjar does drop way below normal, and it becomes drowsy. Many mammals become sleepy, too, without actually hibernating. Bears, badgers, tree squirrels and others go to sleep for varying periods of time, but they wake periodically and may feed on stored food. Their temperature does not drop more than a few degrees below normal, however. True hibernation, where the body temperature falls almost to that of the surroundings, is found in only a few groups of mammals. The egg-laying mammals (e.g. platypus) and some of the opossums are known to hibernate in cold winters. Bats of temperate and cold climates hibernate because they cannot catch insects in winter. Bats are extraordinary, however, in that their temperature drops considerably every time they sleep, even in summer. In this torpid state they use less energy and they can be more active when they are awake.

Some insect-eating mammals, not-

Tree squirrels do not hibernate. They sleep drowsily, waking from time to time in order to feed and also to get rid of waste products that have accumulated within their bodies. The nest is constructed in a hole in the trunk or in a fork.



The African lungfish is able to burrow into mud when its pool dries up. It surrounds itself in slime to keep moist and breathes through a small opening in the slime. The fish is able to survive until the rains return.



(above) The poor-will, a semi-hibernating species of nightjar. (below) (left) Moisture often condenses as droplets on the fur of hibernating bats. (right) A hibernating ground squirrel.

ably the hedgehog, and many rodents (e.g. dormice, hamsters, and ground squirrels) also go into a deep winter sleep. Even so, these hibernators often wake up and may feed on stored food. Ground squirrels certainly do this. It seems that it is necessary for the animal to wake up from time to time in order to get rid of waste materials that have accumulated.

Before they go into hibernation, animals often put on weight, especially in the form of fatty deposits. This extra material is drawn upon in the winter sleep. Others store nuts and other food which they consume at intervals when they awaken.

It is not known what causes these preparations and the internal changes associated are not fully understood. Temperature and lack of food probably contribute to the onset of hibernation, and the length of the day may also play a part.

At the start of hibernation the mechanism by which the animal's body temperature is governed is disturbed and the body temperature falls. As it falls the chemical reactions taking place within are slowed down; breathing slows, as does the heartbeat. If the outside temperature drops too much, however, the heartbeat quickens and the body temperature increases to maintain life.

CHAPTER 12

How many senses?

LIVING things respond to changes in their surroundings. Their success or failure depends on whether they make the right responses or not. Thus a flowering plant survives largely because its roots grow downward into the soil to obtain a supply of water and minerals and because its stem grows upward, so that the leaves can obtain light and carbon dioxide for photosynthesis. In a similar way an animal's responses (at the simplest level) take it towards food and away from danger.

Though experiments on various protozoans show that they are responsive to many stimuli, such as light, heat, touch and chemicals, their responses are limited and generally consist of a random avoiding reaction. *Amoeba*, for example, has no sense organs. The whole of its surface reacts in the same way to a variety of stimuli.

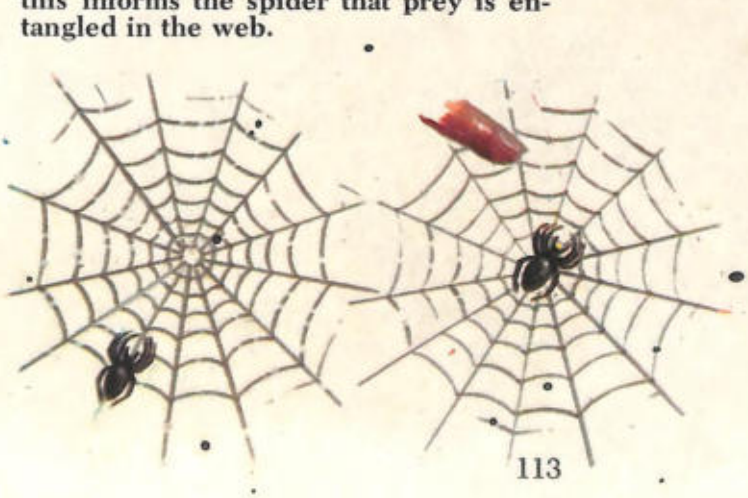
Higher animals possess special sense organs, such as eyes, and are able to make more precise responses. The response to a particular stimulus is not always the same for, in combination with the signals received from other sense organs and the store of information accumulated from past experiences, the 'set' actions of the animal are modified. This is particularly so in Man. A top class tennis player will vary the shots he makes when in similar positions to avoid having his game 'read' by an opponent.

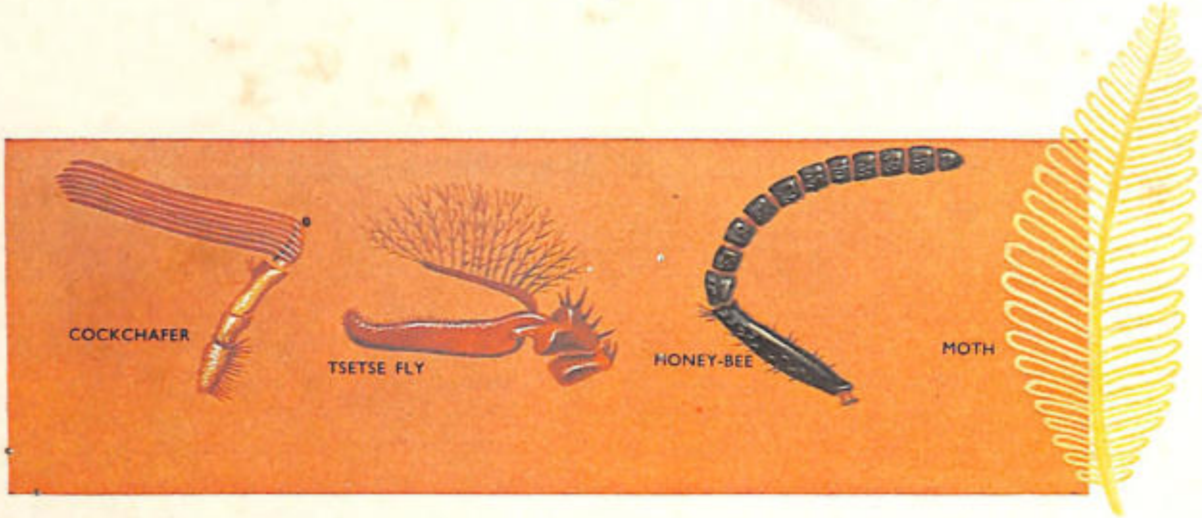
When asked how many senses we possess, most people mention only five – sight, hearing, smell, touch and taste. But in fact there are many more. These include balance and we are also sensitive to heat, cold, pressure and pain. Signals to the brain from sense organs in the gut signify the need for food and we are also aware of thirst.

It is probable that free nerve endings, those not connected with specially sensitive cells (receptors), in the skin act as sense organs. Various

The avoiding reaction in a protozoan, *Paramecium*. On hitting an object it backs away and then moves forward in another direction. If the object is encountered again the movement is repeated until it passes unimpeded.

Web-spinning spiders have sensitive hairs on their legs. The vibration of the web by an object affects the hairs and this informs the spider that prey is entangled in the web.





There is great variation in the shapes of antennae amongst insects. They are particularly well developed in moths for example.

organs that are more complicated have been recognised. Such are pressure receptors, Meissner's corpuscles in the skin, and nerve endings that are coiled around the base of hairs. There are certainly also hot and cold receptors in the skin.

Some biologists dispute whether there are discrete structures for some of these senses. They suggest that the handling of the receptors during their preparation (staining, etc.) may produce differences in structure and they prefer the idea that the way a stimulus is interpreted depends on which nerve tract carries the signals to the central nervous system (brain and spinal cord). Thus, when the endings of the optic nerve (the nerve leading from the eye to the brain) are stimulated, the signals that pass to the brain are always interpreted as light. That is why we sometimes 'see stars' when we receive a heavy blow on the head. The blow stimulates the optic nerve and the brain interprets the signals it receives as light.

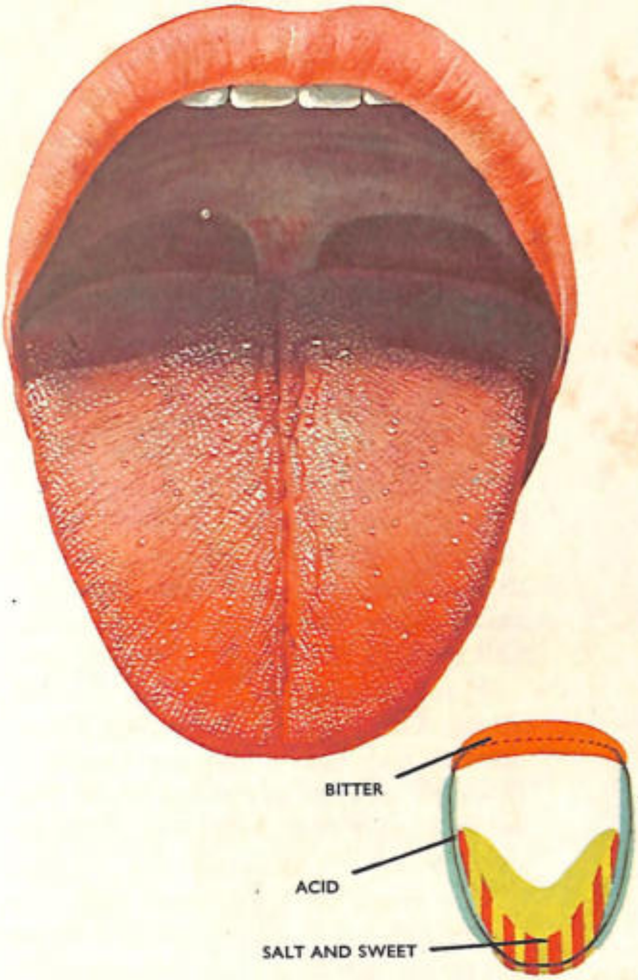
Insects are well equipped with taste and smell receptors. An elephant hawk moth uses its proboscis to obtain nectar from a honeysuckle flower. (inset) The feeler or antenna of a moth (enlarged) on which olfactory (smell) receptors occur.

The simple receptors for the senses described are indeed simple in structure compared with those for sight (the eyes) and those for hearing and balance (the ear). Besides the special canals in the ear, modified nerve endings in the muscles are concerned with the body's balance. The brain is able to sort out all the information that it receives from these various structures automatically and so we stay the right way up without thinking consciously.

The skin is richly supplied with receptors. This is of considerable importance, for the surface of the body is in direct contact with the surroundings. If contact with an object is painful then a part of the body can be moved rapidly away before too much damage is caused. Similarly a pleasant sensation may result in further movement towards the object encountered.

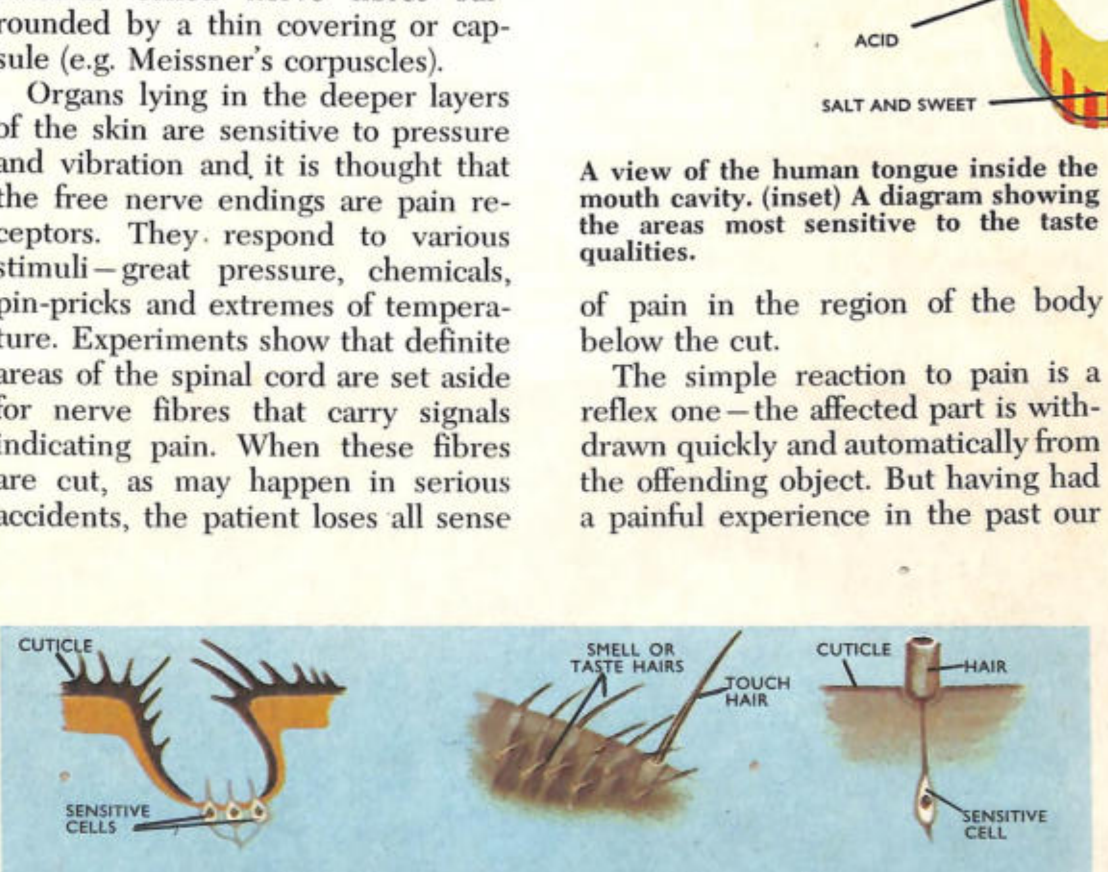
Some areas of the skin are far more sensitive than others. The soles of the feet, the palms of the hands, and the lips are particularly sensitive. Though the skin registers pain and is sensitive to touch, heat, cold and pressure, very few types of receptor have been identified. Free nerve endings have been found in all parts of the skin. The bases of the hairs have nerve endings wrapped round them and the lower layer of the skin contains coiled nerve fibres surrounded by a thin covering or capsule (e.g. Meissner's corpuscles).

Organs lying in the deeper layers of the skin are sensitive to pressure and vibration and it is thought that the free nerve endings are pain receptors. They respond to various stimuli – great pressure, chemicals, pin-pricks and extremes of temperature. Experiments show that definite areas of the spinal cord are set aside for nerve fibres that carry signals indicating pain. When these fibres are cut, as may happen in serious accidents, the patient loses all sense of pain in the region of the body below the cut.



A view of the human tongue inside the mouth cavity. (inset) A diagram showing the areas most sensitive to the taste qualities.

The simple reaction to pain is a reflex one – the affected part is withdrawn quickly and automatically from the offending object. But having had a painful experience in the past our



Insect senses: (left) A pit on an antenna containing smell receptors. (centre) Sensory hairs of various kinds on an antenna. (right) A simple touch-sensitive hair.

muscles are controlled in such a way that an object known to be harmful is avoided.

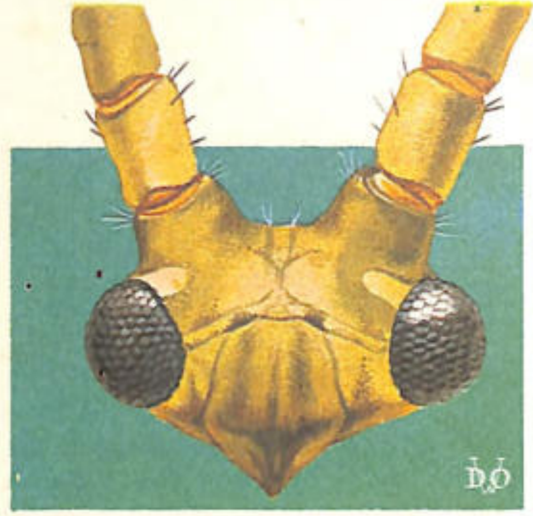
There are also pain receptors inside the body. Various conditions – a duodenal ulcer, for example – give the sensation of pain.

By moving a moderately warm object or a cold object near to the skin numerous 'hot' and 'cold spots' can be mapped out. It is suggested that specific receptors are stimulated, though parts of the skin (e.g. that of the ear) lack receptors other than free nerve endings or nerve endings wrapped around the bases of the hairs.

Touch receptors are of several kinds. The ends of the nerve fibres around hair bases are very sensitive to slight movements of the hairs. The sense organs of the stiff hairs (vibrissae, e.g. 'cat's whiskers') on each side of the snout in many mammals are particularly sensitive (see 'The night life of animals').

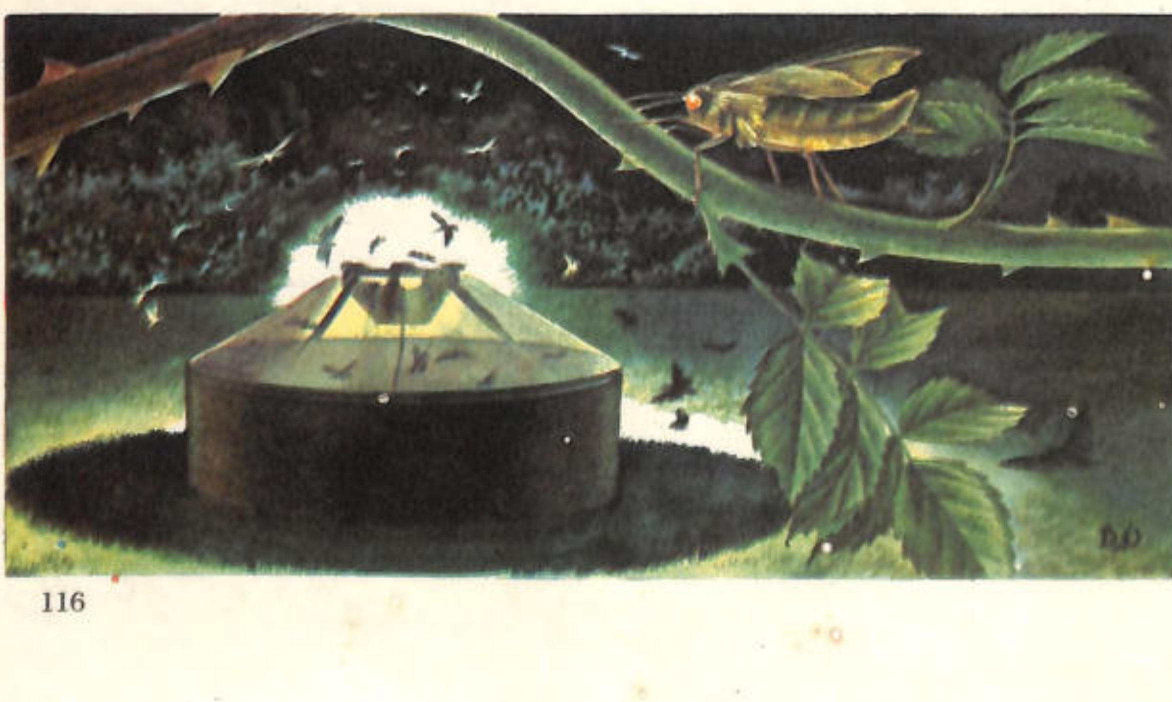
The tips of the fingers are well supplied with receptors. Two types have been identified, both associated with the ridges that leave 'fingerprints'. Meissner's corpuscles are probably sensitive to fairly large disturbances of the skin, whereas other types are stimulated by very light touch. Touch receptors on such parts as the lips are also highly sensitive.

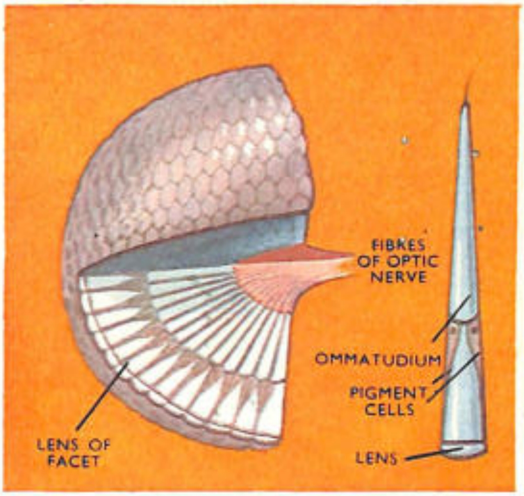
Some of the receptors within the body are sensitive to chemicals. The cells of the part of the brain concerned with controlling our breathing are sensitive to the amount of carbon



The head of a greenfly showing the small compound eyes – each having few units – on the sides of the head.

The human eye is not sensitive to ultra-violet light, but some insects, including moths, have organs that are receptive to radiations of short wavelengths. This trap, used for collecting moths at night, contains an ultra-violet lamp.



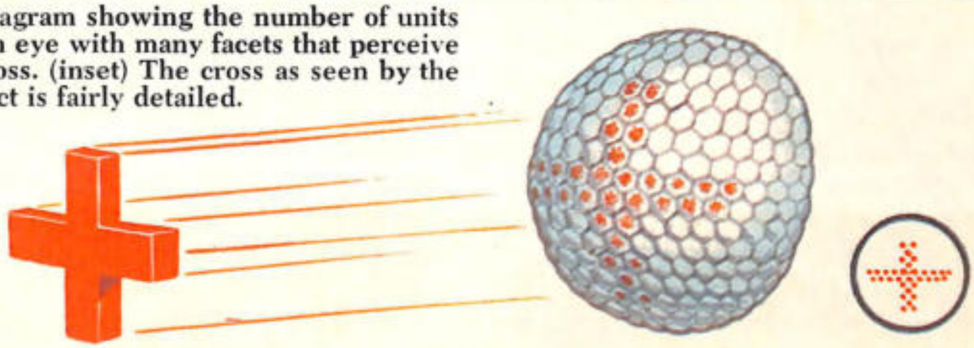


The compound eye of an insect cut away to show the arrangement of the units or ommatudia. (inset) A single ommatudium seen in lengthwise section.

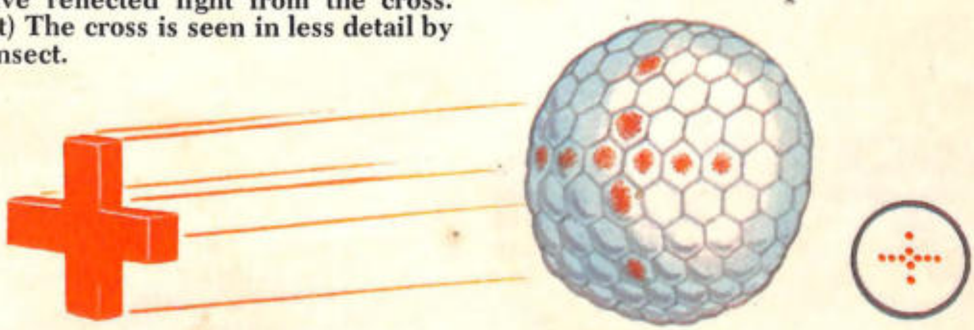
The head of a horse-fly showing the large compound eyes, each of which is made up of many units.

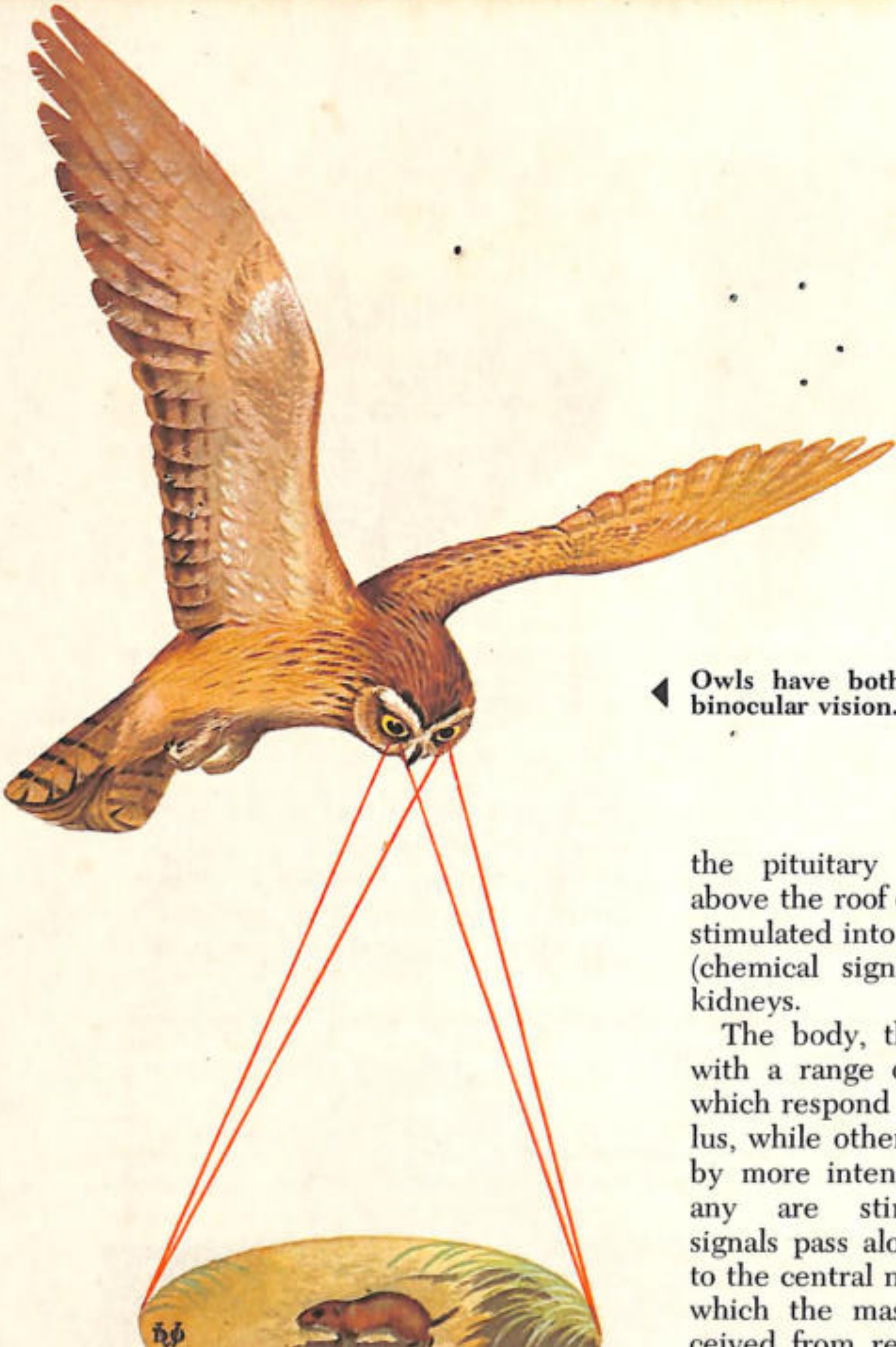
dioxide in the blood, for example. Signals from receptors in the lungs pass to the breathing centre also. Signals pass from the receptors in the heart to a special centre in the brain and play a part in the control of the heartbeat. Cells in one part of the brain are sensitive to changes in the concentration of proteins in the blood. Signals from them pass to

A diagram showing the number of units of an eye with many facets that perceive a cross. (inset) The cross as seen by the insect is fairly detailed.



Fewer units of an eye with few facets receive reflected light from the cross. (inset) The cross is seen in less detail by the insect.



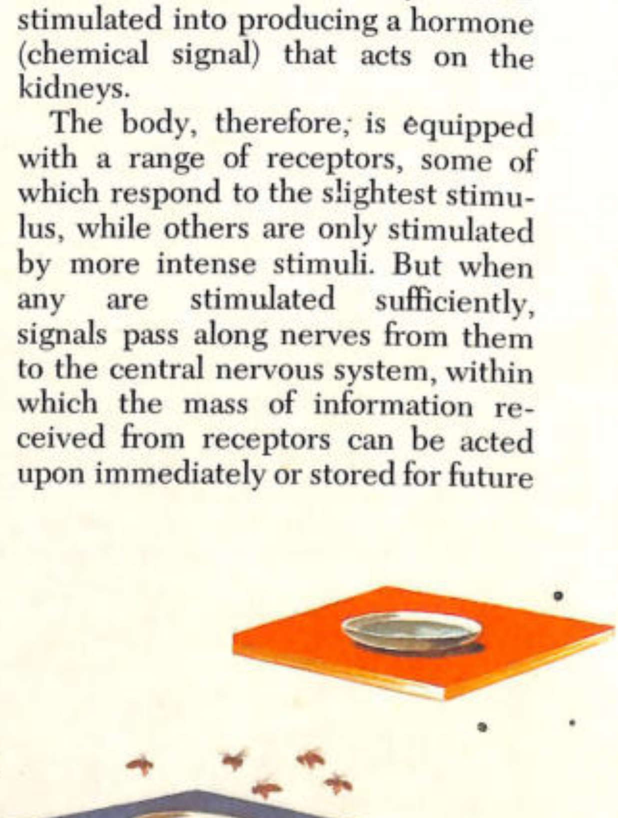


Owls have both eyes at the front for binocular vision.

the pituitary gland, situated just above the roof of the mouth, which is stimulated into producing a hormone (chemical signal) that acts on the kidneys.

The body, therefore, is equipped with a range of receptors, some of which respond to the slightest stimulus, while others are only stimulated by more intense stimuli. But when any are stimulated sufficiently, signals pass along nerves from them to the central nervous system, within which the mass of information received from receptors can be acted upon immediately or stored for future

Experiments on the sight of bees. By placing sugar solution in the dish on the blue paper Karl von Frisch trained the bees to associate the colour blue with food. He showed that they had colour vision by placing several dishes on a chequered board of varying shades of grey with one blue square. The bees collected at the dish on the blue paper.



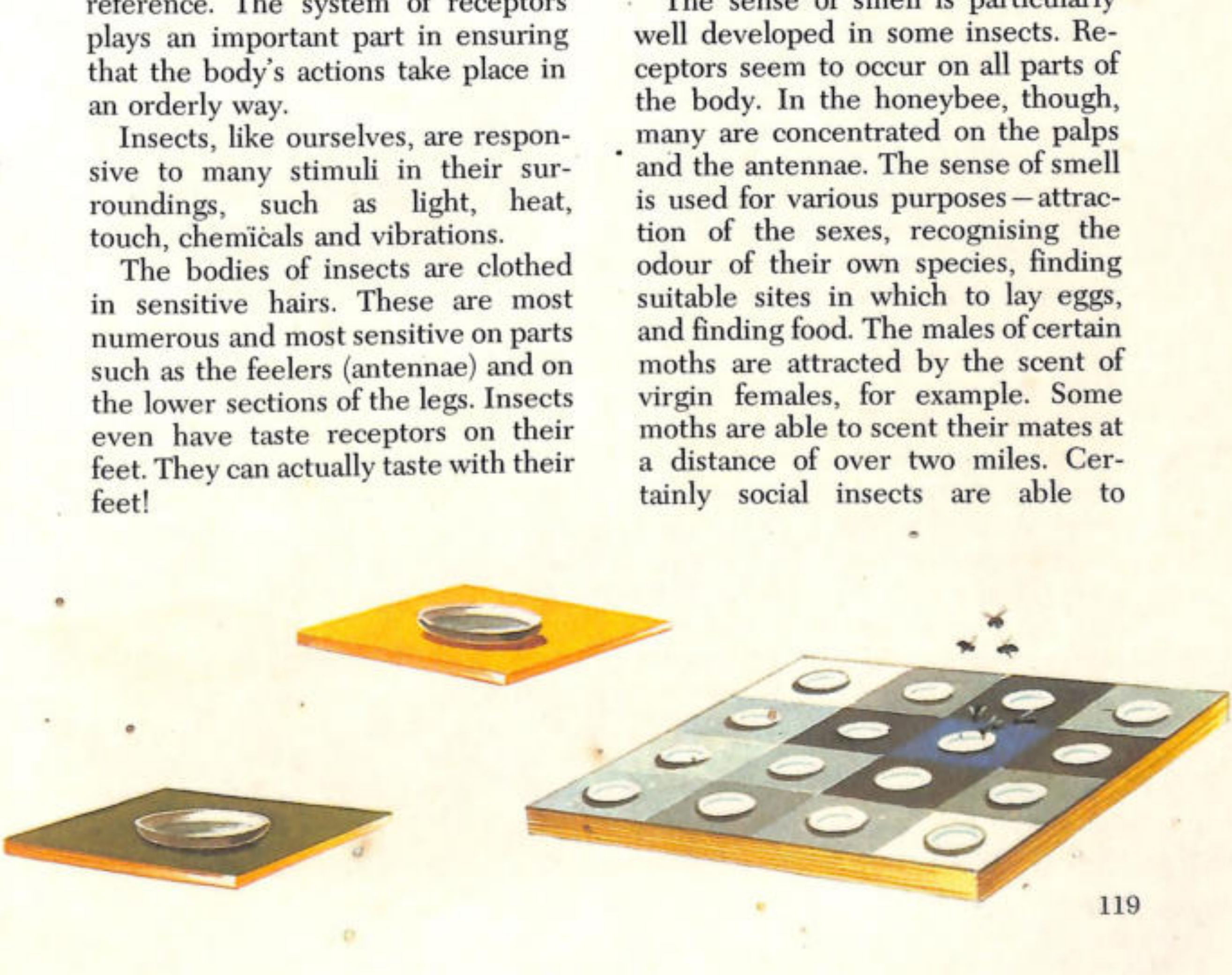
Not all animals see an object in the same colours. The pictures show how a bunch of flowers will appear to Man (A), a dog (B), and many birds and fishes (C).

reference. The system of receptors plays an important part in ensuring that the body's actions take place in an orderly way.

Insects, like ourselves, are responsive to many stimuli in their surroundings, such as light, heat, touch, chemicals and vibrations.

The bodies of insects are clothed in sensitive hairs. These are most numerous and most sensitive on parts such as the feelers (antennae) and on the lower sections of the legs. Insects even have taste receptors on their feet. They can actually taste with their feet!

The sense of smell is particularly well developed in some insects. Receptors seem to occur on all parts of the body. In the honeybee, though, many are concentrated on the palps and the antennae. The sense of smell is used for various purposes – attraction of the sexes, recognising the odour of their own species, finding suitable sites in which to lay eggs, and finding food. The males of certain moths are attracted by the scent of virgin females, for example. Some moths are able to scent their mates at a distance of over two miles. Certainly social insects are able to



The short-horned grasshoppers produce sounds by moving their hind legs against ridges on the wings. Tiny pegs on the legs create vibrations just as the teeth of a comb produce vibrations when they are drawn across a piece of card.

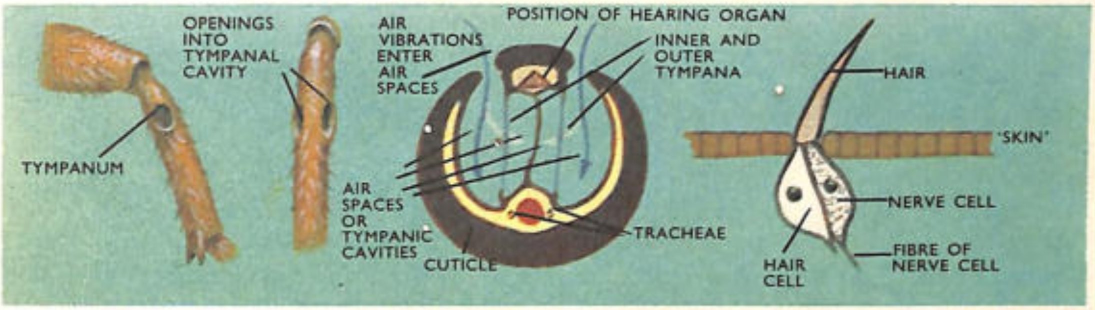
detect members of their own species, even of their own colony. Often an ant of the same species but from a different colony will invade the home of a neighbouring colony. It will be recognised as foreign because its different smell can be detected and so it will be evicted or killed. Some ants will follow trails left by others and so they are guided on their food-foraging expeditions.

Many insects have excellent sight. It is certain that some can see colour but none can see the colours that we do to the same extent. However, although insects can barely detect red as a colour many can see ultra-violet light which we cannot see. In fact, moth traps use light that contains large amounts of ultra-violet light.

The compound eyes of insects are so called because they are made up of many lens units, unlike the human eye which has only one lens. Insects with excellent vision, such as dragonflies, have many units in each eye so that they receive a more distinct view of their surroundings than an insect with eyes made up of very few units, such as greenfly.

Not all insects can hear but those that do often have organs for making sounds as well. Examples are crickets.

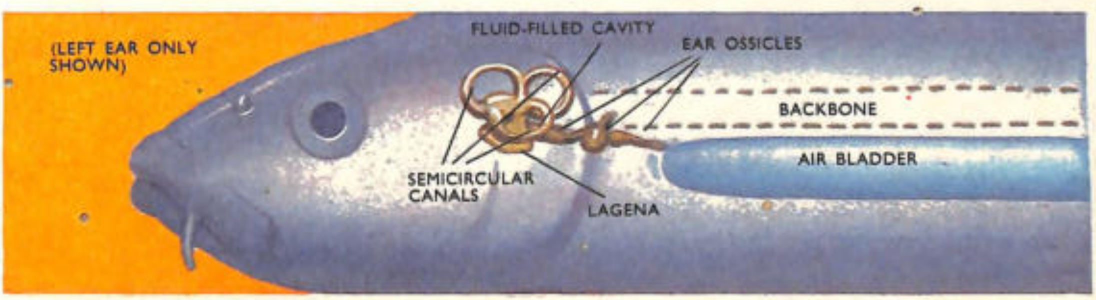
Fishes have a unique system called the lateral line system (in fact it is also found in the young stages of frogs). Along the sides of a fish, from head to tail, a prominent line can be seen. This is the lateral line.



(left) Side view and front view of the hearing organs in the legs of a cricket. (centre) A section across the leg of an insect showing the sensitive part of the hearing organ and the tympana (drum skins). (right) A hair that is sensitive to sound waves.

A pattern of similar lines can be seen on the head. They are made up of separate groups of highly sensitive cells arranged in long rows. The cells are protected either within a groove or in a tube underneath the skin which opens to the outside through short tubes, arranged almost at right angles to the main tube. Each cell has a hair-like projection sticking up into the water in the groove or tube. Movements or vibrations in the surrounding water move the hairs and the disturbance of the sense cells results in nerve signals passing to the brain. The fish is then able to take the appropriate action.

The lines on the head are particularly well developed in fishes such as herring that feed on minute floating organisms in the surface waters of the sea. It is possible that the system plays an important part in detecting food. One deep-water fish has lateral line organs on stalks projecting from the sides of the body. Food is scarce in the abyssal regions of the sea; is it possible that this extraordinary development of the lateral line system helps to detect prey? Alternatively, of course, it would be equally valuable in detecting disturbances of the water due to enemies.



Carp-like fishes have a chain of bones between the air bladder and the ear apparatus. Vibrations can be transmitted along these to the ear.

CHAPTER 13

Animal behaviour

THE thrush is not taught to build its nest nor the garden spider to spin its web. These are instincts—actions which are inborn and which do not have to be learned.

Instincts are common in the animal kingdom, particularly amongst the lower orders of life. They account for much of animal behaviour—courtship displays, protective care of the young, migratory drives and reaction to dangers. The pattern of behaviour begins usually after a stimulus to one or more of the sense organs. Such a stimulus is called a releaser. A loud noise—and instinctively, animals take evasive action, fleeing or crouching motionless to the ground. Instincts such as nest-building and web- and cocoon-spinning are perfect from the start. Caterpillars of different species of moth spin their own types of cocoon once only in their lives—but they do it perfectly. Young birds reared in isolation away from parents nevertheless build exactly similar nests even down to the material used. Other instincts such as Man's instinct to walk take time and practice to become perfect.

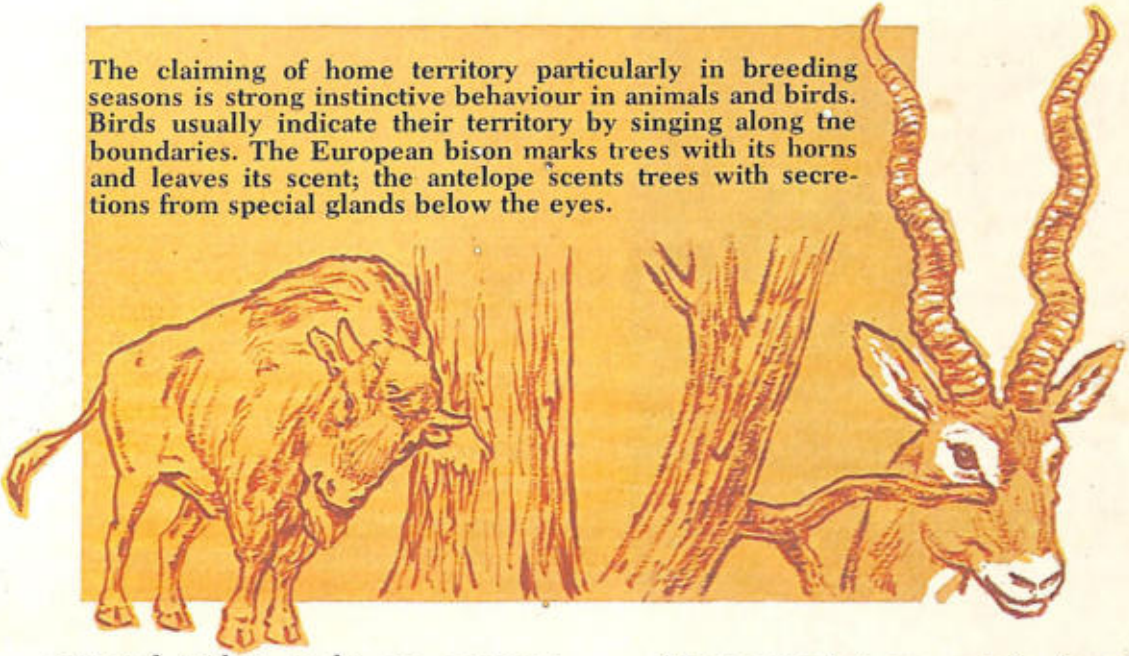
Each species of animal has its own different range and type of instinct. All members of a species will usually behave in much the same way to a stimulus. Instincts are just as much a part of an animal as the structures which identify its body.

Instincts are purposeful. Although carried out without any learning or reason, they fulfil a definite and usually valuable role. Some are simple enough; a mole bites off the heads of worms it wishes to store for food. The body of the worm remains alive, but devoid of its head it cannot burrow and escape. More complicated are the engineering feats of the beaver. The beaver fells trees, transports them along specially constructed canals and builds them into dams.

A variety of instinctive behaviour is associated with courtship in different species. The bold parading of pheas-

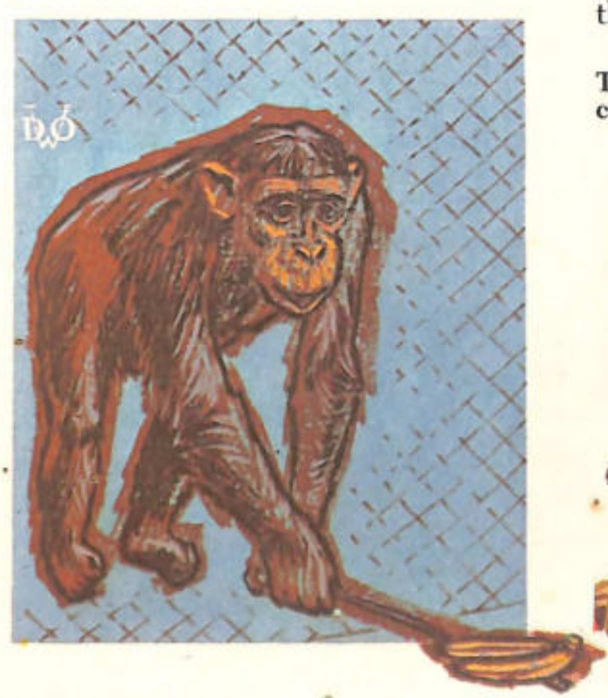
A chick inside an egg shell instinctively pecks its way out into the world. Without this instinct the chick would suffocate inside the egg. What can be eaten, and what cannot, is learned. At first, the chick pecks at anything—pebbles and wood. By association it learns what objects make good food.

The claiming of home territory particularly in breeding seasons is strong instinctive behaviour in animals and birds. Birds usually indicate their territory by singing along the boundaries. The European bison marks trees with its horns and leaves its scent; the antelope scents trees with secretions from special glands below the eyes.



ant and turkey cocks are common examples. Male redstarts hold a singing contest, ringed plovers demonstrate their powers of flight, while deer and many other animals engage in contests of strength.

This chimpanzee shows signs of insight-learning. Without previously encountering this situation, it uses a bamboo stick to reach out and drag bananas into its cage.



More amazing are certain impulsive instincts to emigrate from a region. When their populations become overcrowded in Norway, hundreds of thousands of lemmings begin a colossal mass migration from their homes. Unless a new unoccupied territory is reached the migration continues. The death rate is enormous for the fleeing lemmings are easy prey; many more drown in the rivers and seas they encounter.

The woodpecker finch uses a tool – a cactus spine – to extract insects from bark.

Defensive mechanisms are instinctive. They do not have to be learned. The porcupine erects its quills and rattles them when danger threatens. Cats spit and ruffle their fur; some animals such as the octopus produce frightening colours.

The opossum has a curious defence mechanism. It pretends to be dead. It becomes limp, its eyes close, its heart slows down. When danger is past the creature quickly revives.

The caterpillar of the puss-moth. when disturbed, withdraws its head under its thorax. The thorax, as a result, swells and displays two prominent eye-like lumps. In addition, a pair of whiplashes (modified prolegs) beat the air over the caterpillar.

Similar emigrations have been observed in the springbok of South Africa. Less drastic are the seasonal migrations of birds and animals. Regular passages are made from areas where reproduction takes place to regions in which winter is spent.

Self-preservation is a universal instinct in the animal kingdom. Yet when rearing young, the instinct to protect the offspring is often even stronger. Many mammals and birds will stand and fight an aggressor when normally they would have fled. Ground-nesting birds such as the sky-lark may put on a decoy display. When an aggressor appears, near the nest, the parent bird attracts attention to itself by screeching and flapping its wings.

Because there is no forethought or reasoning behind instincts, their function sometimes becomes impaired. One male penguin, for instance, incubates the egg laid by the female, by supporting it on its foot. If no egg becomes available the penguin will obey its instinct by substituting a round stone. Birds feed their young because the sight of gaping mouths is the releaser to supply food. It does not matter whether it is their own young or not —food is pushed into any gaping mouth. Blackbirds have been known to feed the hungry young of great tits; foster-parents feed the young cuckoo hatched in their nest without any hesitation.

Instincts regulate the lives of animals like pieces of machinery. An outside action takes place; this provides a stimulus and a fixed pattern of behaviour takes place. Animals which rely largely upon instincts—nearly all except some of the mammals and birds—lack personality.

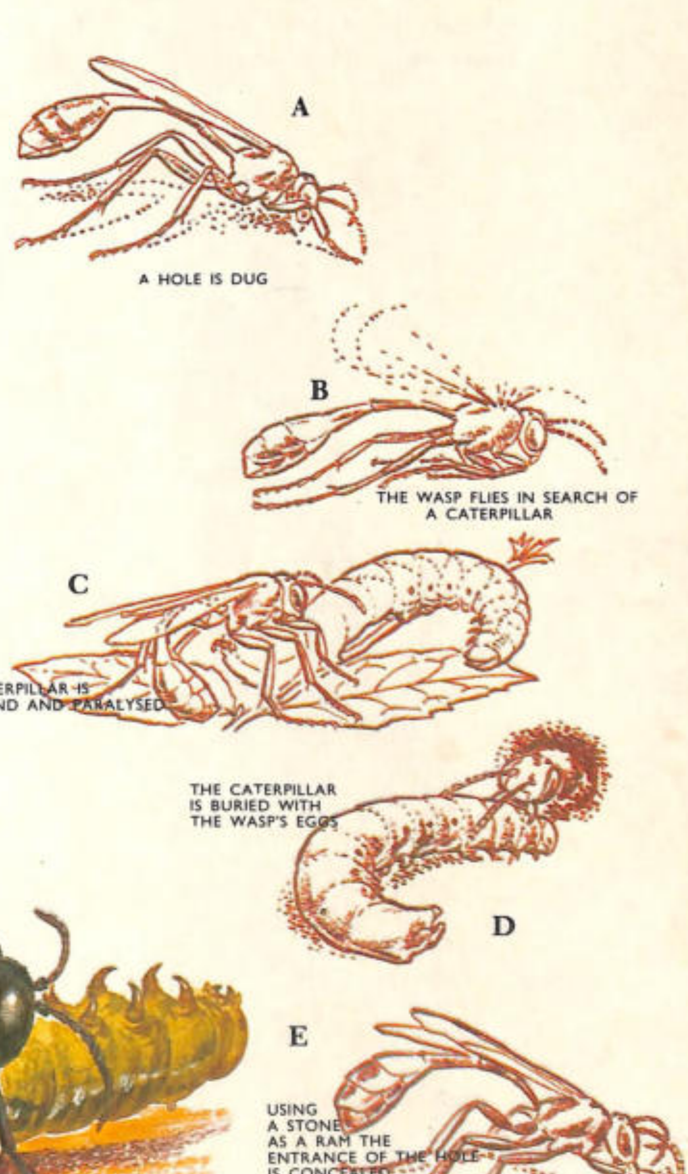
They all behave in much the same way as other members of their species.

Escape from this internal machine is to some extent possible—by a process of learning. Learning has the effect of modifying the instinct. Actions no longer take place blindly but are conditioned by past experiences. Two simple types of learning are habituation and association. In habituation the initial instinct is lost. Though the old stimulus occurs there is no reaction to it. Domestic animals for instance no longer flee from Man. Association (or conditioning) takes place when the original stimulus is replaced by another. Domestic animals may no longer associate Man with danger but instead with food or comfort.

Association is the method by which animals remember. An encounter leading to an unpleasant experience is avoided at a future date. An encounter which ended in a reward will be repeated. In this manner animals can be trained.

The ability to 'remember' exists to some degree even in simple animals such as snails and worms. By experience with mild electric shocks they learn to avoid making journeys that will bring them in contact with the

This species of hunting wasp performs a complicated series of tasks before laying its eggs. The female digs a hole in the ground. Then she seeks a caterpillar. When one is found she stings it—not to kill but to paralyse—drags it to the hole and lays eggs upon it. Later the grubs hatch and eat the caterpillar. The wasp has never seen another wasp perform the task; nor will she see the young eat the caterpillar. The whole process is done by instinct.



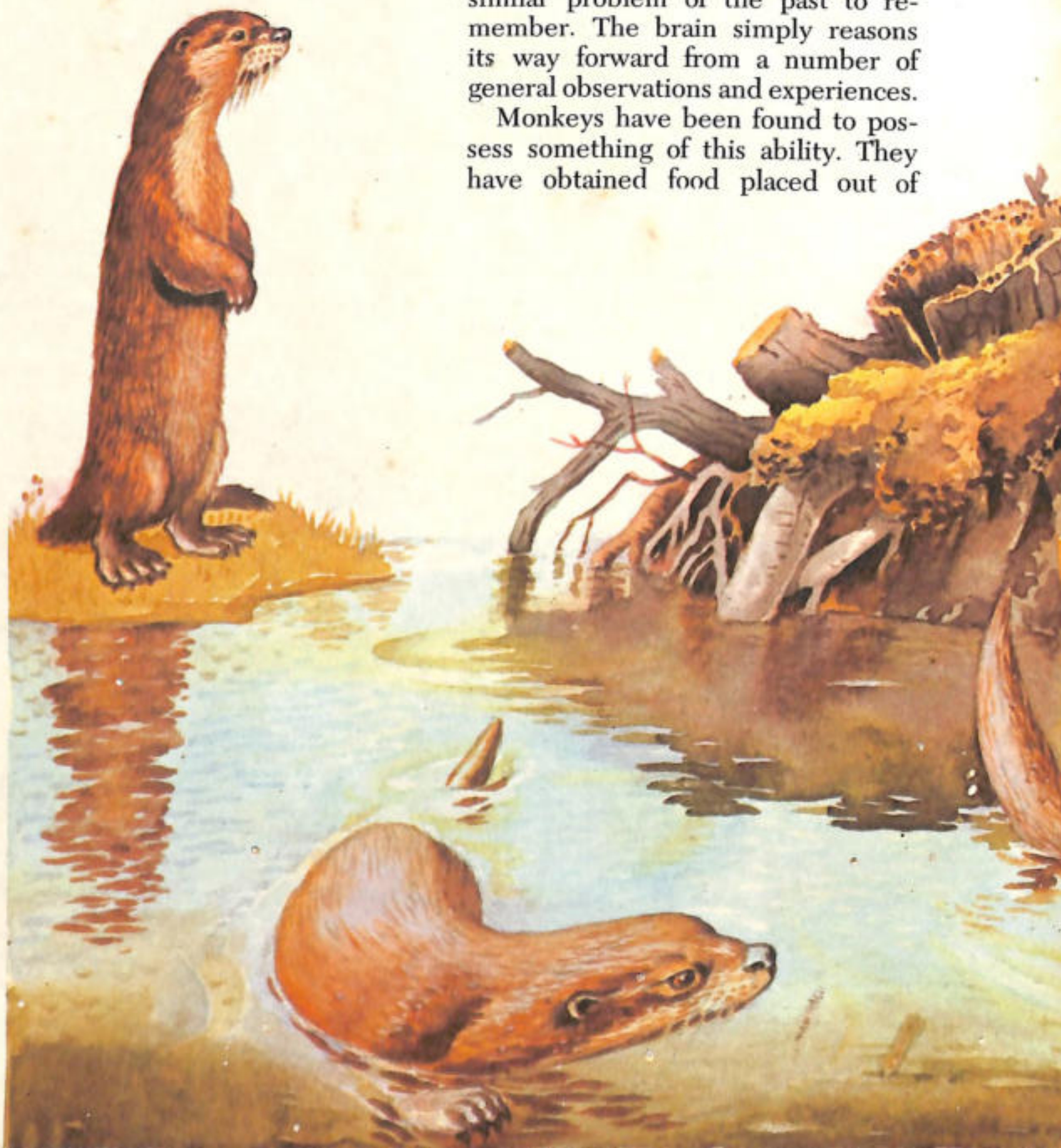
AMMOPHILA – A HUNTING WASP

shock. Bees and wasps certainly have the ability to learn. They soon recognize the landmarks surrounding their nests or hives and are able to move about without losing their way.

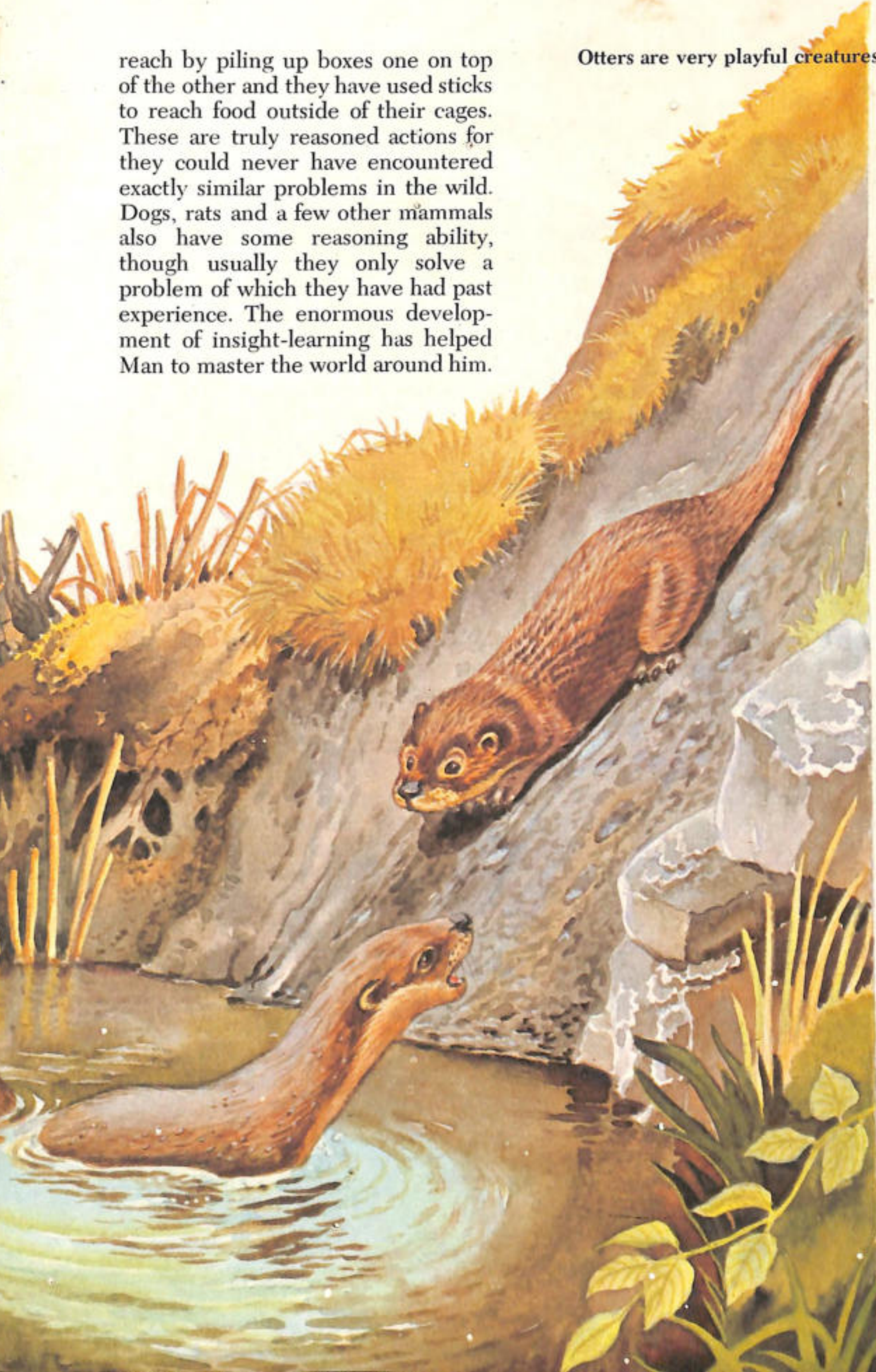
By trial-and-error an animal builds up solutions to a number of problems. A dog attempting to reach food on the other side of a fence may come across a hole in the fence. He remembers the hole on future occasions and when presented with a different fence may again search for an outlet. In this way dogs appear to reason though all they are doing in fact is remembering similar past situations.

Man not only has the ability to learn by trial-and-error but has developed a further type of learning. This is insight-learning—the ability to think out a situation before taking any action. A completely new problem never encountered before is overcome by reorganizing all previous experiences. A solution is found not by the long and troublesome method of trial-and-error, nor is there a similar problem of the past to remember. The brain simply reasons its way forward from a number of general observations and experiences.

Monkeys have been found to possess something of this ability. They have obtained food placed out of



reach by piling up boxes one on top of the other and they have used sticks to reach food outside of their cages. These are truly reasoned actions for they could never have encountered exactly similar problems in the wild. Dogs, rats and a few other mammals also have some reasoning ability, though usually they only solve a problem of which they have had past experience. The enormous development of insight-learning has helped Man to master the world around him.



Otters are very playful creatures.

CHAPTER 14

The social insects

THE majority of insects lead solitary or individual lives. Apart from a brief courtship and mating period they do not come into close contact with each other. Eggs are laid and abandoned, the parents rarely surviving to see their offspring. The young have to fend for themselves, each seeking food and shelter for itself. This state of affairs is far removed from that in a beehive where the female parent is long-lived and produces large numbers of offspring which work together for the good of the community. The honey-bee is a social insect. This term is used for those insects in which parents and offspring actually live together in one nest and co-operate in running the community. The social insects are found in only two orders of insects—the termites or 'white ants' group, and the bees, wasps and ants group. As in other animals (e.g. birds and mammals) the family group is the basis of the community.

The common earwig shows a certain degree of parental care. Eggs are laid in a shallow pit and guarded by the female. The young nymphs stay with the mother for a few days before they disperse, but there is no co-operation in feeding. Social behaviour probably arose from associations of this type. Many of the solitary bees and wasps show levels of behaviour very similar to those through which the true social insects must have passed. These solitary insects live alone as adults but their nest-forming habits qualify them for inclusion among the sub-social insects. Solitary bees and wasps differ mainly in that the wasps feed their young with animal food such as caterpillars, while bees rely on vegetable food—pollen and nectar. The solitary bee *Prosopis* is very wasp-like. It has a simple proboscis (tongue), an almost hairless body and no pollen-collecting apparatus. It is likely, therefore, that bees developed from wasp-like insects and began to collect vegetable food for their young. The adults all feed on vegetable material.

The female *Prosopis* bee, after mating, finds a suitable reed stem and constructs tiny cells within it. As each cell is finished the bee regurgitates a small amount of pollen-nectar mixture into it and lays an egg there. The cell is then sealed up and a further one made. Only about half a dozen cells are produced and the bee then dies—before any of the eggs hatch. The larvae feed upon the food provided and after pupation fly away to mate. The male bees do not live long after mating.

The potter-wasp—*Eumenes*—is at a similar level to *Prosopis*. It constructs tiny vase-shaped cells of soil and provisions them with caterpillars before laying eggs and sealing the cells.

Cells of the nest of the common wasp showing various stages of development with a worker attending a cell and (inset) the nest of a tree-nesting wasp cut away. ▶

The small bee *Halictus quadricinctus* makes a small burrow in the soil and constructs a few chambers in each of which an egg is laid. The larvae which hatch are fed regularly by the parent. This is called progressive provisioning as against the mass provisioning of *Prosopis*. When the larvae are full-grown the parent seals up the cells and dies before the young bees emerge. A wasp of the genus *Stenogaster* has a similar history except that the parent survives until its offspring emerge. They live together in the nest—usually a group of hanging cells—for a while but do not co-operate. A further step towards social life is shown by bees of the genus *Allodape*. The eggs are laid in a hollow stem and fed by mass or progressive provisioning. When the young females emerge they remain at the nest and help to feed the younger larvae for a while before flying away to mate.

The bee *Halictus malachurus* is even more highly organised. In spring the females construct small burrows and brood cells which they mass provision with honey and seal up after laying an egg. The first offspring to emerge are all females, but they are not quite like their mother. They are, in fact, worker bees. Instead of deserting the nest they proceed to make more cells and to collect pollen and nectar. The original parent or queen ceases to go out and confines herself to laying eggs in the cells made by the workers. This is a case of true co-operation and social life. About August males and normal females (i.e. not workers) appear and mate. They continue to frequent the nest but do no work. Only the new queens survive the winter and begin the cycle again in spring.

The bumble-bees and social wasps have much larger nests than *Halictus malachurus*. The workers are smaller than the queens and are physiologically different. Bumble-bees store pollen and honey in case of bad weather and do not give all collected food direct to the larvae. In Britain their colonies are always annual

◀ **A wild bee colony in a hollow tree.**

A worker bee attending to larvae in cells of the comb.

affairs but in tropical countries they may last many years like those of the honey-bees. The queen bumble-bees and wasps hibernate during winter and then start to build in spring. The bees make their nests in old mouse-holes and the like, and construct their cells with wax. Wasps use various sites for a nest and construct their cells with wood-pulp rasped from dead trees and other wooden structures. The common wasp constructs an underground nest. The first few cells are made round a small root or some similar object and eggs are laid. Gradually, more cells are added until an umbrella-like structure is formed. The cells all open downwards. A further tier of cells is then added below and a complete nest, covered with 'wasp-paper', may have eight tiers or combs. For a long while the only offspring produced are female workers which carry on building the nest, leaving the queen to lay eggs. Towards the end of summer male and queen wasps are produced but only the mated queens survive the winter.

Honey-bees are more advanced than the bumble-bees and wasps. There are greater differences between the three forms; queens, workers and males (drones). The perennial nature of the colony points to a tropical origin for the honey-bees. New colonies are started not by a queen alone but by a queen plus a swarm of workers which leave the parent colony and set up elsewhere. Hollow trees are suitable natural homes. The queen plays no part in comb-building or food gathering and becomes merely an egg-laying machine. She lacks the pollen combs and other structures for foraging and building. The larvae in the cells of

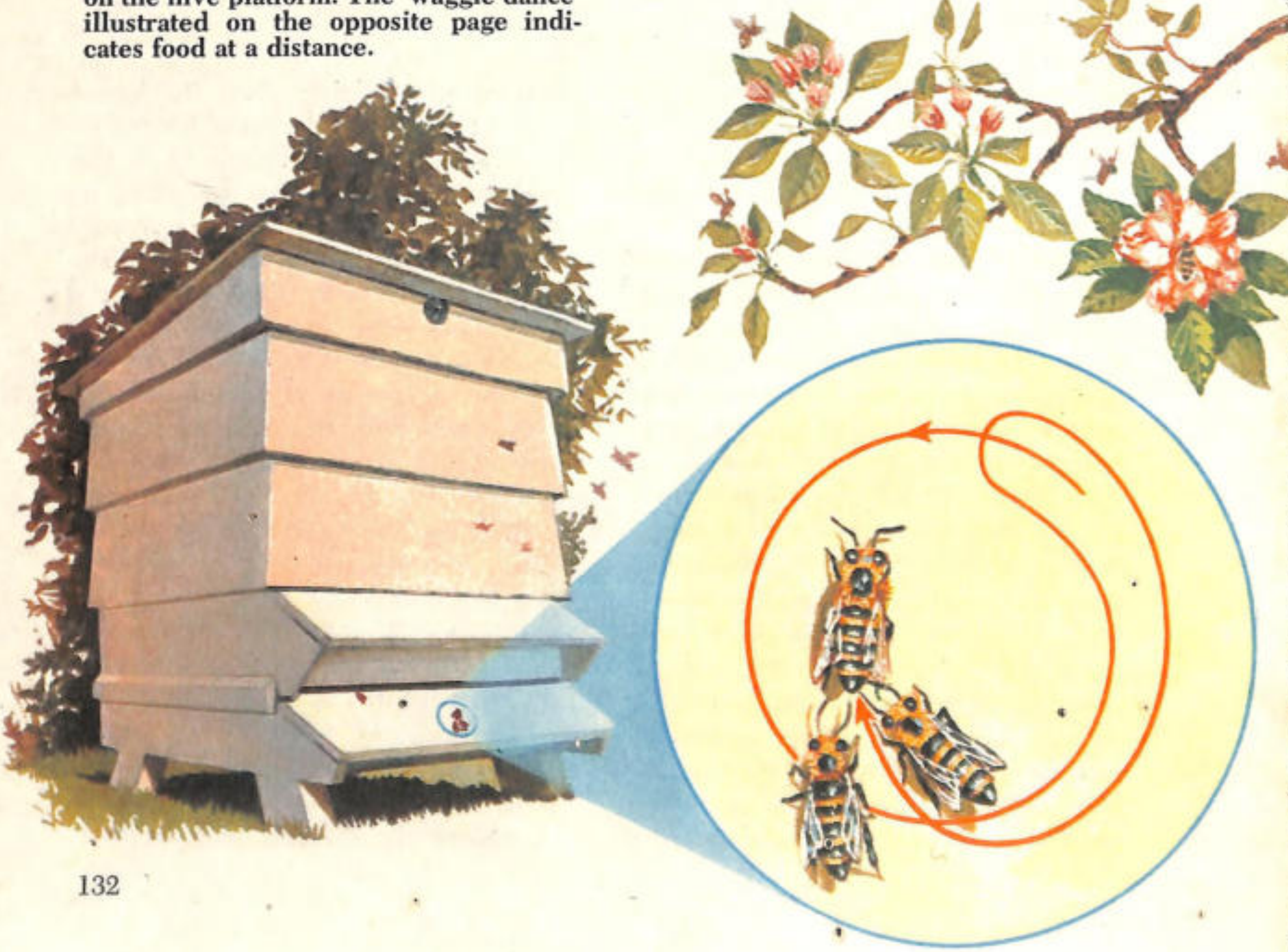
A worker fans scent from her scent gland (arrowed) to inform others of the whereabouts of a food source.

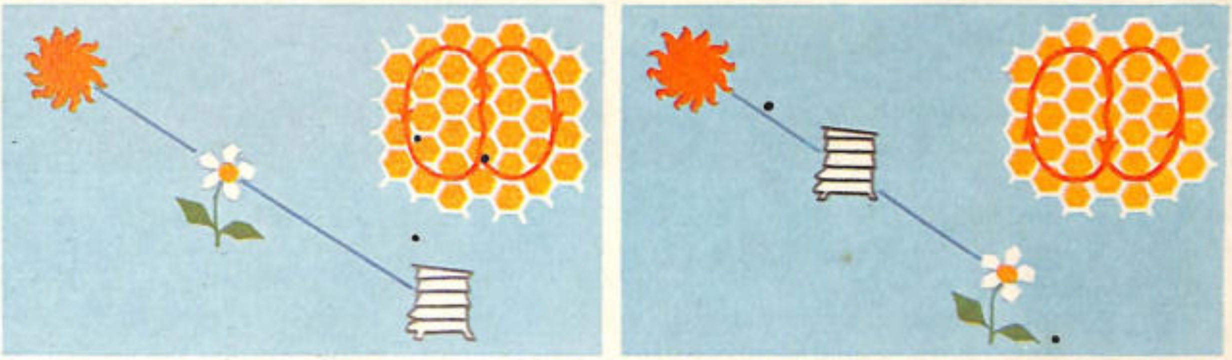
the comb are fed by workers. There is a certain degree of division of labour among the workers. The younger workers are normally concerned with looking after the larvae and do not go out foraging for pollen until later. Many 'household' duties such as comb-building and cleaning are also performed. Every now and then large cells are produced and the larvae in them are fed on special food. They develop into new queens. When a swarm occurs it is the old queen which leaves the hive. The new ones literally fight for control of the nest. A full-grown colony may contain 60,000 or more workers. Drones are normally reared only in summer. Spring and autumn broods are all workers.

Honey-bees are able to communicate with one another by means of dances. In this way information is passed on about position and distance away of sources of nectar and pollen.

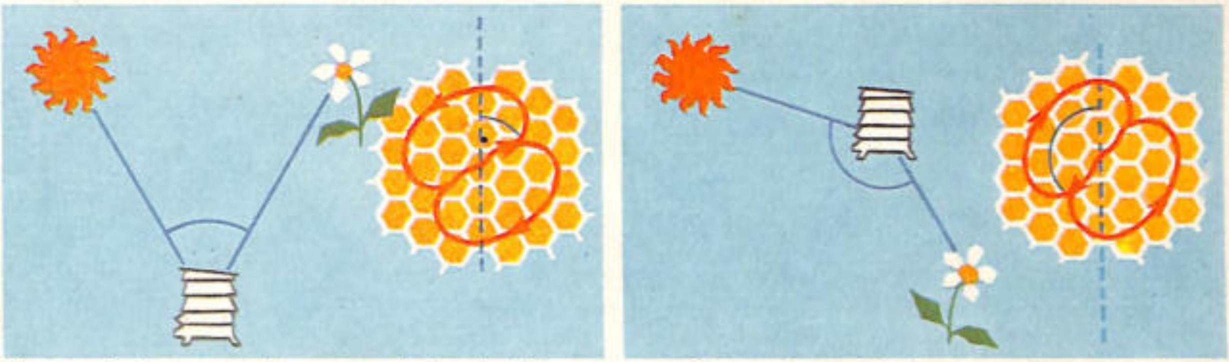
In the insect societies so far described the females play the dominant part. The same is true among ants. All ants are social and are a very successful group of insects. A few species (e.g. the army ant) make no permanent nest but move from place to place in search of any animal food. Those species which do construct nests normally do so underground. Ant nests usually contain far more individuals than bee or wasp nests. The nest may be started by a mated female, alone, or with a few workers. No brood cells are constructed—the young are reared in chambers in various parts of the nest. There are both carnivorous and vegetarian ants. Many actually keep aphids in the nest and feed upon the sweet secretions given up by the aphids. The division of labour is even more marked in ants than in bees. In some species there are several types of workers, each adapted for a special role. The soldier ants, for instance, have very large heads and jaws with which they defend the colony against intruders. The mating swarms of ants are annual events which occasion much comment. The males and reproductive females (queens) are winged and emerge from the nests in large numbers all at the same time. After mating the males die and the mated females break off their own wings and proceed to make a nest.

Honeybees communicate the finding of food nearby through the 'round dance'. In sunny weather this may be performed on the hive platform. The 'waggle dance' illustrated on the opposite page indicates food at a distance.





Communicating about a distant source of food. (left) When the food supply is in the direction of the sun the 'straight run' is vertically upwards on the comb. (right) The straight run is downwards when the bees must fly away from the sun.



The angle between the sun and the food is transposed into the angle between the vertical and the line of the 'straight run'. The bees then fly at this angle to the sun and reach the food.

The termite group is a primitive one far removed from the bees and wasps, yet the termites live in highly organized communities. They are common in the tropics and two species extend into Europe. Termites feed mainly upon cellulose and are serious pests of timber. They make nests in trees or underground—sometimes making huge mounds on the surface. The soil particles are mixed with saliva and harden into concrete-like structures. The termites are unlike the other social insects in that the males and females are equally important. The mated pair, after their 'wedding flight', form a colony together. They live together in a special 'royal chamber' and are fed by the workers. The queen becomes little more than an egg-laying machine. Unlike the other social insects, mating occurs several times during the life of the queen. There are other reproductive forms in the colony and these can produce more workers but cannot produce kings and queens. The workers and soldiers are of both sexes and carry out the construction and defence of the nest and the food-gathering work. Tunnels from the nest often lead for long distances to food-gathering grounds. It is remarkable how closely the termites resemble ants in their way of life when one considers how unrelated they are. The name 'white-ants' reflects this similarity.

Ants are all social in habit and, partly for this reason, are considered to be more highly advanced than

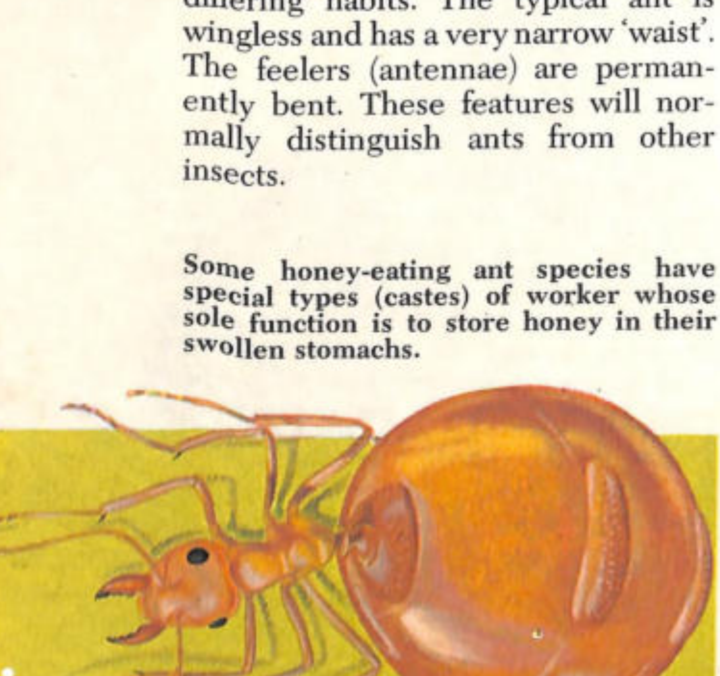
Weaver ants preparing to sew leaves together with silk produced by the larvae.

The wood ant queen (top), male (top right), mated queen (now swollen with eggs) and worker.

wasps, bees and termites. Unlike the colonies of wasps and many bees that perish each autumn, leaving only the mated queens, the ant community is perennial. Individual ants may live for several years.

There are, throughout the world, a great many species of ant of widely differing habits. The typical ant is wingless and has a very narrow 'waist'. The feelers (antennae) are permanently bent. These features will normally distinguish ants from other insects.

Some honey-eating ant species have special types (castes) of worker whose sole function is to store honey in their swollen stomachs.



Nest-building habits are very varied; in fact some species do not build permanent nests at all. The 'driver' ants of the tropics roam around continually searching for living and dead animal food. They may temporarily inhabit hollow logs and the like but are soon 'on the march' again. Many ants make their nests in the ground. The soil removed in the excavation of chambers and galleries may or may not be heaped up into a mound. Some species (for example the wood ant) make 'hill nests'—excavated soil is heaped up with leaves and other material and the heap itself is full of run-ways and chambers. Other nests are made under logs and stones, in tree stumps, or even among leaves fastened together with silk. The inhabitants of such nests may vary in number from a few dozen to several hundred thousand in a large wood ant nest. In no cases are there any elaborate brood combs such as are found in bees' nests.

It is interesting to note that among the ants there are 'hunting', 'herding' and 'agricultural' species. This parallels the development of human cultures especially as the most primitive ants are the hunters (i.e. the 'driver' ants and their relatives). Many ants obtain 'honey-dew' from aphids (green fly) by stroking them. Some ant species even keep the aphids in the nest. These ants may be regarded as being 'herders'. A number of species collect plant food and store it, but a group of ants known as the Attini actually cultivate their food. They feed upon certain types of fungus which they grow in the nest. A number of chambers are set aside for this purpose and floored with leaf-fragments and ant droppings. The fungus grows readily on this material and produces numerous swellings which are harvested by the ants. When a queen ant forms a new colony she carries some of the fungus with her in a pouch in her mouth.

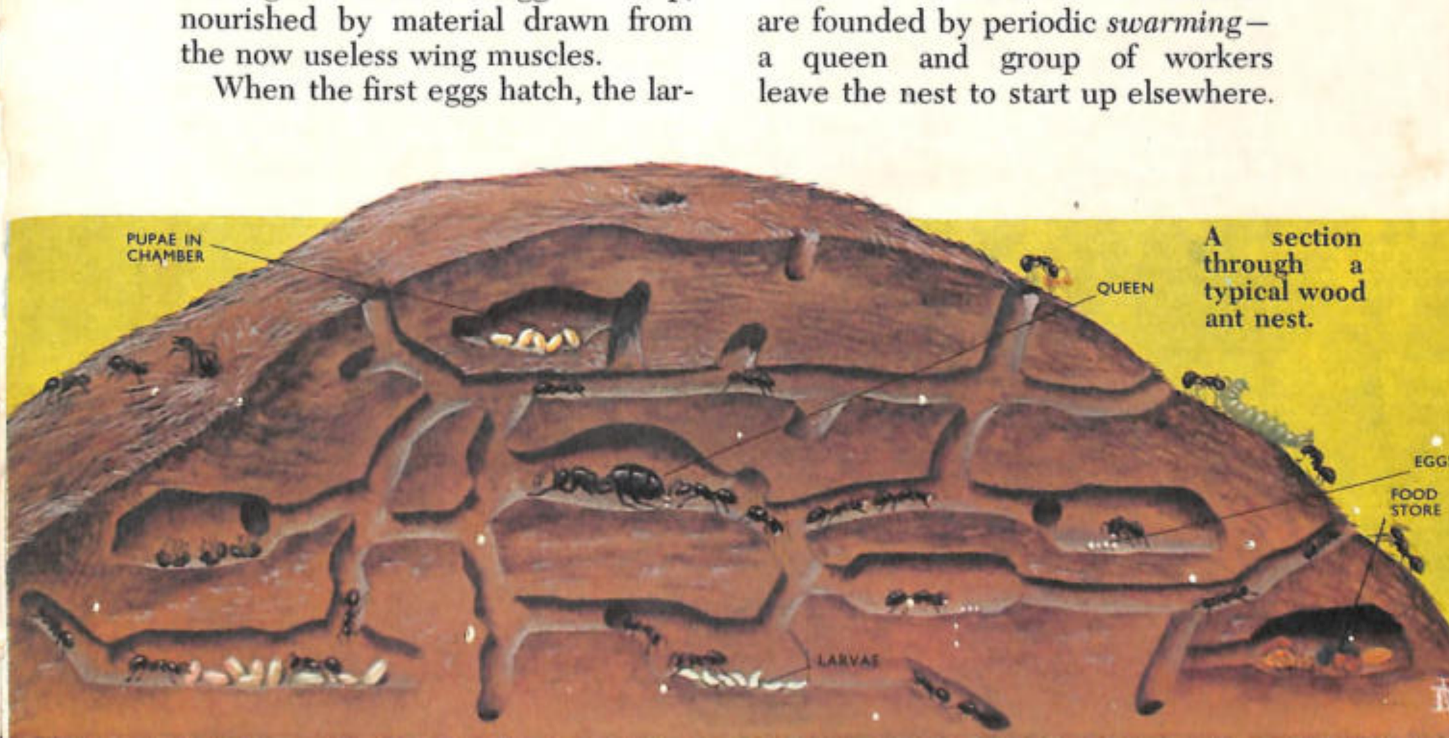
The black garden ant shows, in its life-history and colony formation, the typical features of ant life. It normally nests in the soil, making small mounds. During the summer, winged male and female ants are produced. As a result of some climatic conditions, usually affecting colonies over a wide area, all these winged ants emerge in a short space of time. This phenomenon is the 'nuptial flight' during which pairing occurs. After this the male ants usually perish but the mated females (queens) begin their duties as nest-founders. First, they break off their wings and then they find or make small holes in which to rest for up to several months. During this time the eggs develop, nourished by material drawn from the now useless wing muscles.

When the first eggs hatch, the larvae are fed on saliva by their mother. They develop into wingless workers and begin immediately to work on the nest. The queen then devotes herself entirely to egg-laying. She is fed by the workers throughout the rest of her life, which may be fifteen years or more in some species of ant.

Worker ants make up the bulk of the colony. They are all females and differ from the queens in having no wings and only poorly developed sexual structures. In some ant species there are various types of worker. Those with large heads and powerful jaws are called 'soldiers'. They guard the colony and attack invading ants and other insects. Other workers collect food, and look after the young.

The eggs, larvae and pupae are kept in separate chambers of the nest and are carefully looked after. The larvae are not only fed but are also 'washed' by the workers. The latter eagerly consume drops of saliva exuded by the larvae.

Mated queens do not always found a new colony. They sometimes return to the old nest or to another established colony, which then has one or more queens. This is the normal case in wood ants. New colonies are founded by periodic *swarming*—a queen and group of workers leave the nest to start up elsewhere.



A section through a typical wood ant nest.

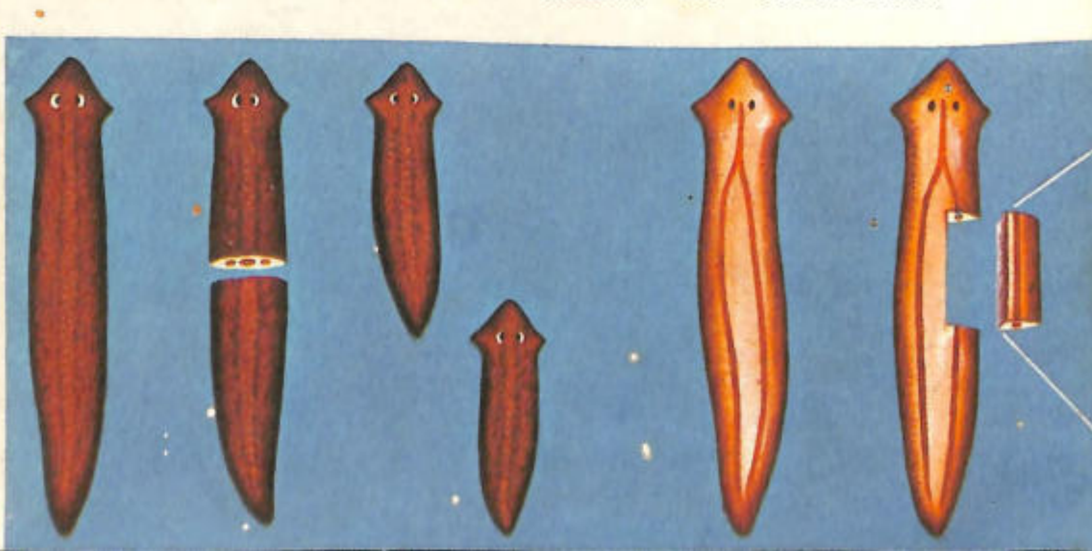
CHAPTER 15

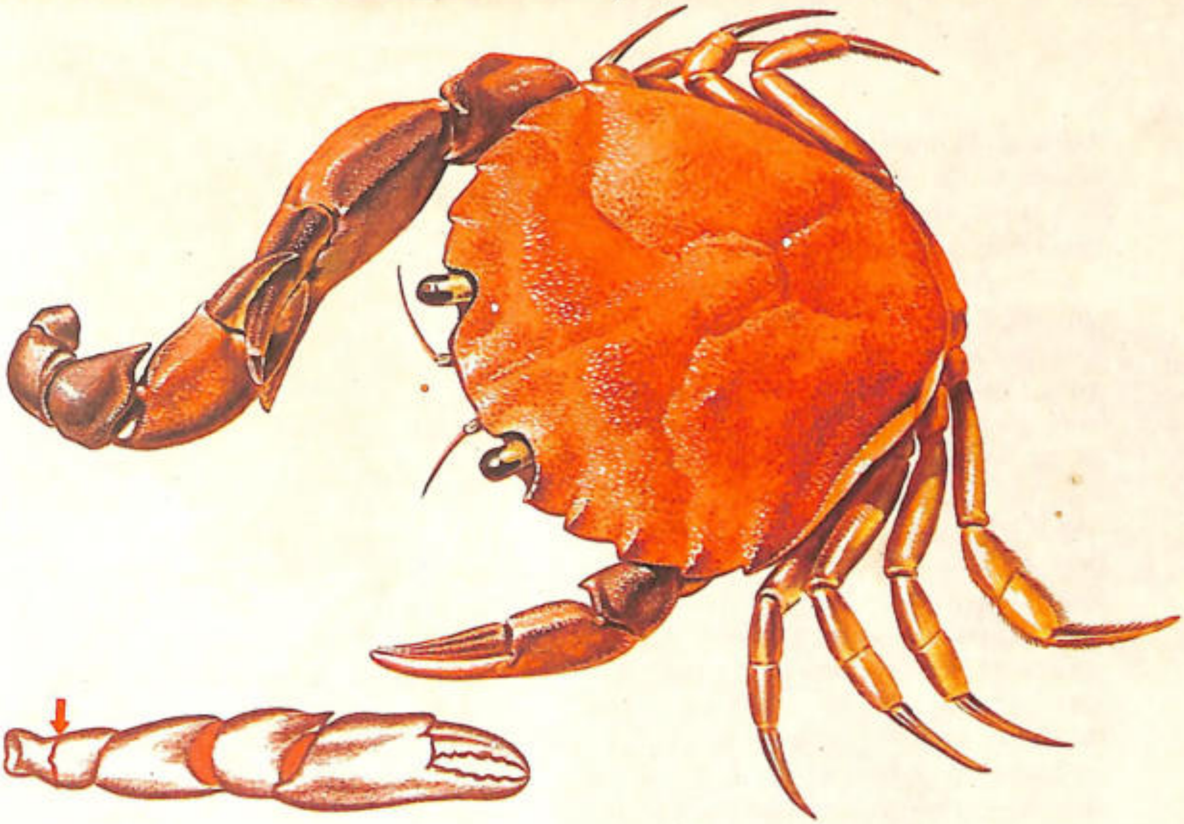
Regeneration

Crabs are able to break off their limbs at a particular point (arrowed) in order to escape from enemies. New limbs will grow and become fully formed after one or more moults.

EACH species of plant or animal has a characteristic form that distinguishes it from other species. The typical form is reached by complicated development from the fertilized egg. When, by some accident, part of the structure is damaged or lost, the organism strives to regain its original form. This ability to grow replacement parts is called regeneration. In general, the rate of regrowth is proportional to the amount of regrowth required to reach the original form. All animals and plants are capable of it to some extent but, as a general rule, the more highly evolved an animal is, the less are its powers of regeneration. Man, for example, is able to regenerate skin and bone tissue to mend wounds and fractures, but he is unable to regrow even a finger if one should be lost. Some internal organs can be regenerated if a large enough part remains as a starting point. The liver is an example; so, too, are the adrenal glands. The replacement of worn-out tissues is a form of regeneration and goes on throughout life. The most obvious is the replacement of skin from below as the outer layers rub off.

Some animals are able to regenerate new limbs—in fact lizards may actually shed their tails to confuse enemies and later they grow new ones. Crabs, too, can throw off a limb to escape from an enemy. The most striking cases of regeneration, however, are found among the lower animals—the coelenterates





(jelly-fish and their relatives) and the flatworms.

Flatworms are built up of three basic layers: an external ectoderm, an endoderm lining the gut, and a mesoderm occupying the space between the two. Planarians are flatworms with great powers of regeneration. As long as all three types of tissue are present, a complete new worm can grow from a tiny portion.

When a planarian is cut in half, both halves can form new animals. The cells of the damaged region lose their individuality and all become alike. They grow and divide and the growing mass takes on the correct shape—be it of a head or a tail. Gradually the cells become specialized again and begin their normal functions. The head region is the co-ordinating region and, if

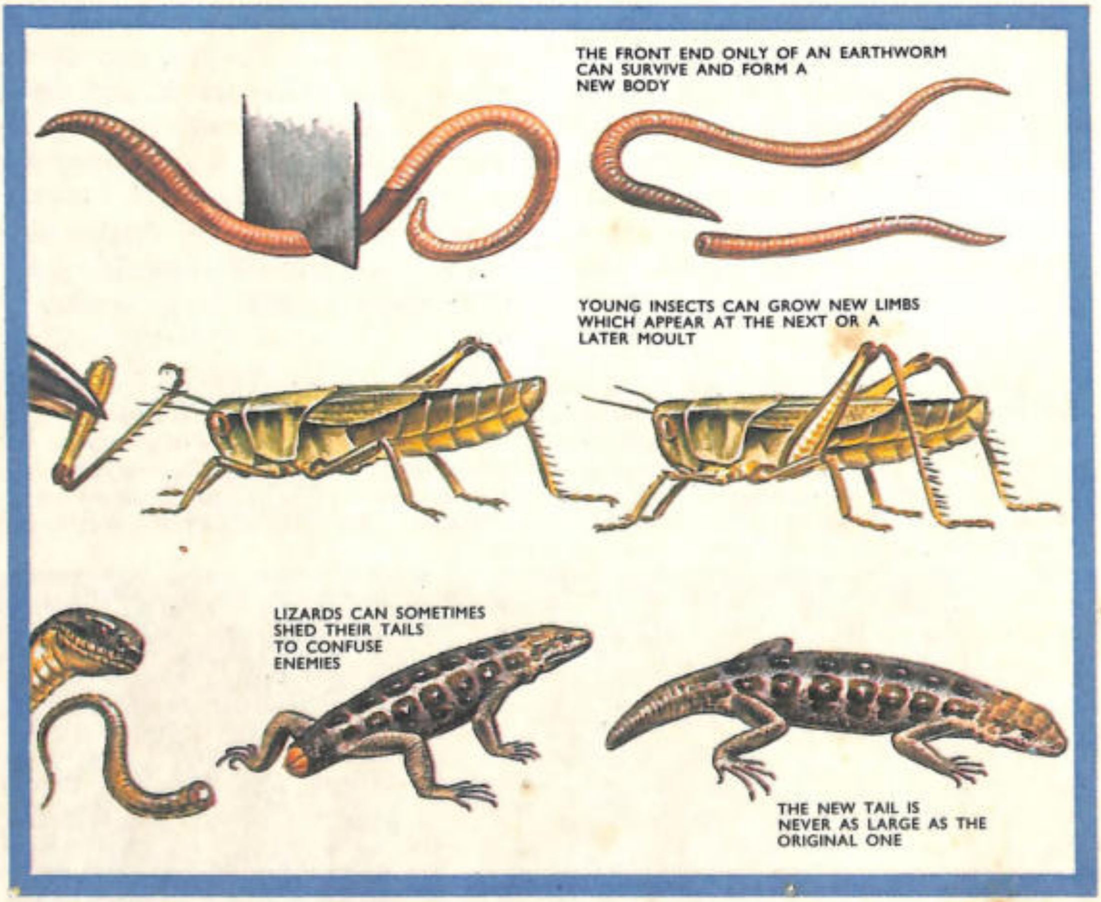
If a flatworm is cut in half each piece will regrow. The front quickly grows a tail, but the tail has to form a head before forming the missing organs. A whole new flatworm can regenerate from a tiny portion, providing skin and gut cells are present. The enlarged drawings show what happens to the flatworm fragment as it is reorganised to form a tiny flatform the size of the fragment. Gut and skin cells become unspecialised. These then divide and eventually take on special tasks again when they are sorted into their correct positions to form a new flatworm.

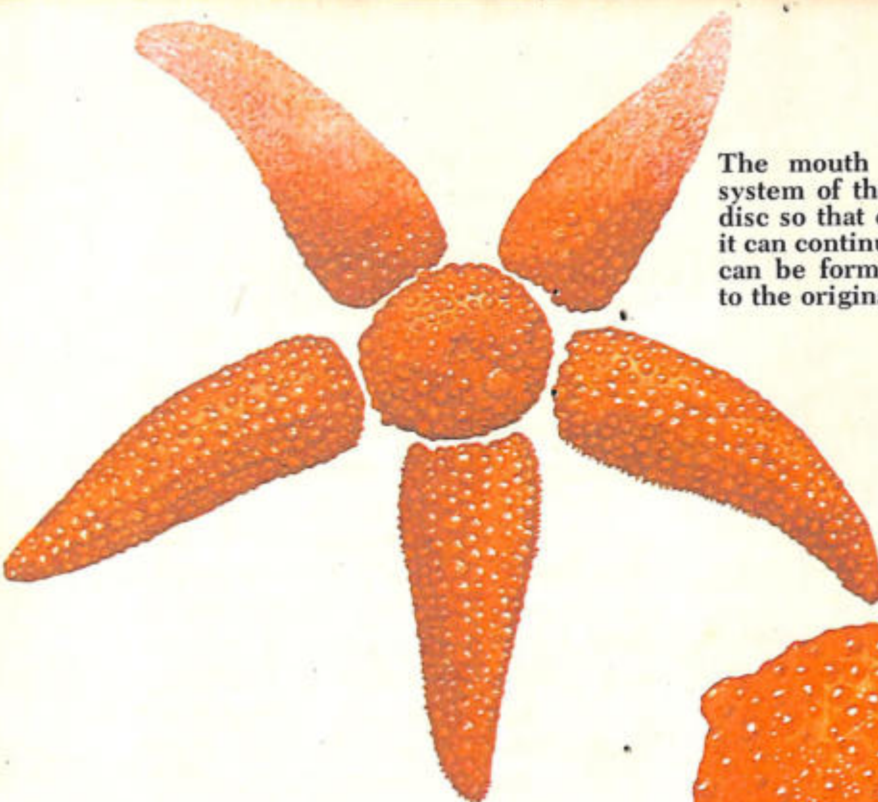
missing, is always the first formed structure in a regenerating body. Not until there is a head can the other organs be re-formed.

A fragment of a flatworm can regenerate into a new individual as long as there is sufficient food reserve in the tissue. The fragment has no mouth and feeding organs and so cannot get any food from outside. The cells at the cut surface (sometimes all the cells in the fragment) become alike and multiply. Because food is used up during this process, the fragment gets smaller, but if sufficient cells can be formed, a tiny planarian will develop. Any original organs remaining in the fragment will be partly absorbed so that they conform in size to the rest of the new animal. A new head is formed before the rest of the body develops.

Any fragment of a planarian that regenerates naturally will produce a head at the original front end. Although the cells are completely reorganised they never lose this head to tail identity or polarity. Regeneration in jellyfish is very similar, but in higher animals the head cannot be regenerated. New limbs and bodies can form under the influence of the head but not vice-versa.

Earthworms are able to regenerate new bodies as long as the front part containing the vital organs is present. The tail region of a worm, if removed, cannot continue its





The mouth and part of the digestive system of the starfish are in the central disc so that even if all the arms are lost, it can continue to feed. In time, new arms can be formed from the disc and grow to the original size.

existence. Crabs, lobsters and crayfish are able to break off their limbs at will—a process called *autotamy*. More important, they are able to regenerate the lost parts. At the base of each limb is a special muscle which bends the limb until it breaks at a specially weakened place, the *breaking point*. At first only a miniature replacement limb is formed, but when the animal next sheds its skin the limb grows rapidly to almost the size of the original limb.

Insects, too, possess the power of regeneration, when young. Missing legs and antennae (feelers) can be regenerated but do not develop fully until after at least one moult. A pad of regeneration tissue develops at the wound and forms the missing limb. Many abnormalities of regeneration are known among insects—a mantis has, for example, been known to grow a leg where an antenna had been lost.

One frequently sees starfishes with one or more arms missing. The mouth and part of the digestive organs are in the central disc of the animal and thus it can continue to feed even when all the arms are lost. Its powers of regeneration are such that the starfish can develop new arms from the central disc alone.

Regeneration in vertebrate animals is much more limited. Lizards can regenerate lost tails but rarely is the new one full sized. Newts have been known to regenerate limbs and tails, so too have young frogs. In the higher animals, the powers of regeneration are confined to the mending of broken bones and connective tissues and the regrowth of some damaged internal organs.

CHAPTER 16

The new generations of plants

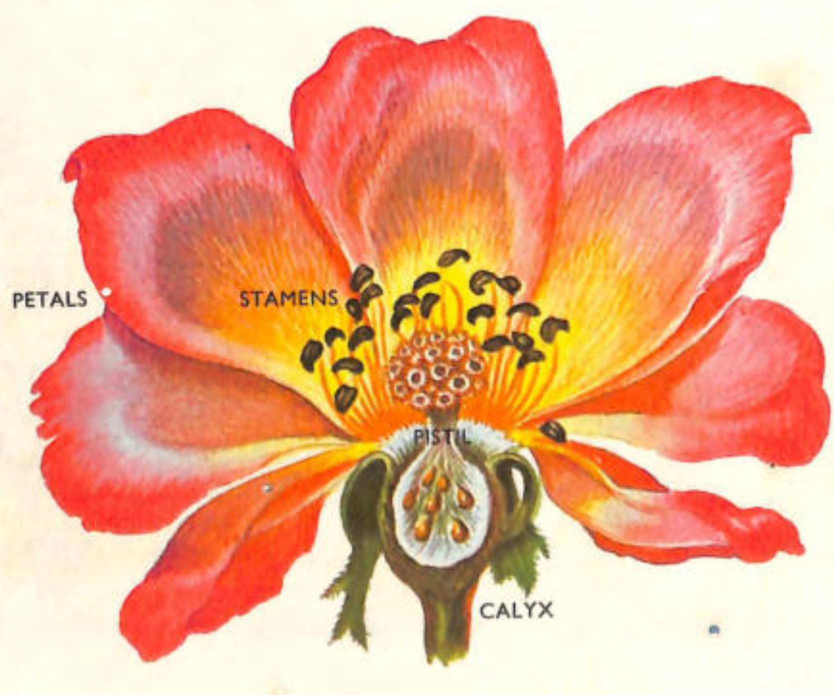
NO PLANT is able to live for ever, so that unless it reproduced itself its species would die out and disappear from the face of the earth. It is imperative that a high proportion of the plants of each particular kind reproduce before they die.

The very simple single-celled plants may reproduce merely by dividing into two, but the majority of plants have flowers in which seeds are produced.

A typical flower has its parts arranged in four rings. The outermost is the calyx (sepals), then in order come the corolla (petals), the stamens and the carpel(s). The stamens and the carpels are called the essential parts since the male pollen cells and the female egg cells or ovules, respectively, are developed in them.

When pollen is transferred from the stamen of one flower to the stigma of another cross-pollination is said to have taken place. If pollen is transferred from the stamens to the stigma of the same flower then the process is, known as self-pollination. When seeds are produced after cross-pollination the resulting plants are often stronger than if the seeds were formed by self-pollination. It is not surprising therefore that most flowers have some way of avoiding self-pollination and ensuring cross-

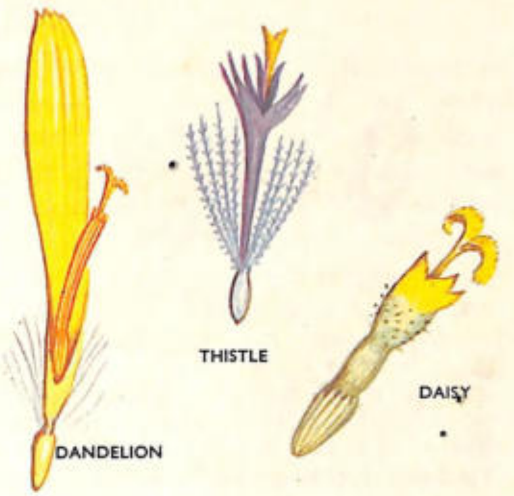
A typical flower cut through the middle to show its structure.



pollination. Those flowers that are adapted to ensure cross-pollination will produce stronger and more successful offspring, which in turn will be adapted for cross-pollination.

Most flowers contain both stamens and carpels but a number of plants have flowers of one sex only. A few species, such as willow, even bear the male and female flowers on different plants. In these cases self-pollination is impossible. Where there are organs of both sexes in the same flower, self-pollination is avoided by having the anthers and stamens positioned in a suitable way, or they develop at different times so that when the pollen is ripe the stigmas are not ready to receive pollen, or alternatively the stigmas may ripen before the stamens.

Although cross-pollination is preferable, self-pollination is better than no pollination at all, and in some flowers the stamens and stigmas bend towards each other before the flower dies so that self-pollination may occur if cross-pollination has failed.



Florets of dandelion, thistle and daisy.

Although insects are the most important agents of pollination, there are others, notably wind. Wind-pollination occurs in many trees and in all grasses. The flowers are typically carried in catkins or the stamens have long stalks. In either case even slight air movements release pollen. The pollen is light and produced in large quantities for it is largely a question of chance as to whether pollen reaches another flower or not. In wind-pollinated

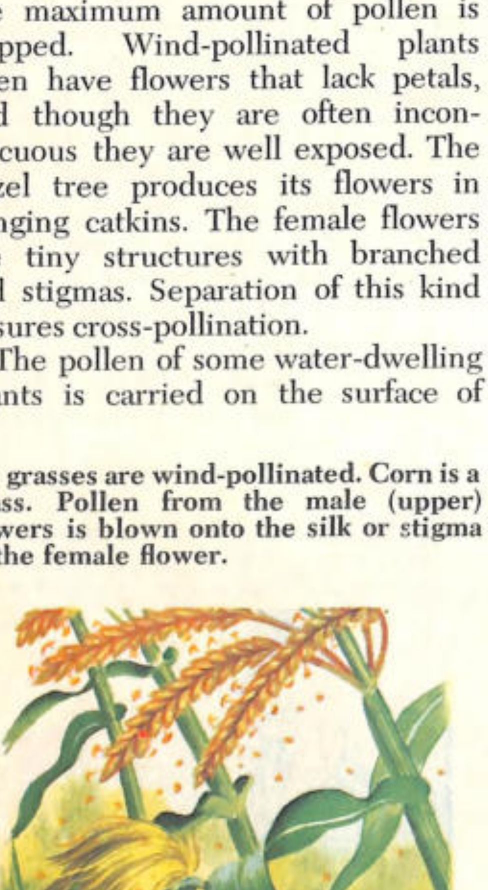
In the mountain laurel the stamens are held in pockets in the petals. The stigma sticks out and touches the body of an insect as it prepares to alight and so receives pollen from another flower. The force of an insect landing releases the stamens which dust it with pollen.

The pollen grains of a species of plant have characteristic shapes and markings. (from left to right) Pollen of oak, chrysanthemum, cosmos, and plantain.

plants the female stigmas are usually large and feathery so that the maximum amount of pollen is trapped. Wind-pollinated plants often have flowers that lack petals, and though they are often inconspicuous they are well exposed. The hazel tree produces its flowers in hanging catkins. The female flowers are tiny structures with branched red stigmas. Separation of this kind ensures cross-pollination.

The pollen of some water-dwelling plants is carried on the surface of

All grasses are wind-pollinated. Corn is a grass. Pollen from the male (upper) flowers is blown onto the silk or stigma of the female flower.



the water, floating in the current or drifting in the wind, until it reaches another flower at the surface.

Both pollination by the wind and by water is very wasteful because large amounts have to be produced to increase the chances of some reaching another flower.

Insect-pollination is by far the commonest and most efficient method of pollen transference. Many flowers have no special structures and can be pollinated by almost any insect, but the more specialised flowers can be pollinated by only a few species of insect. Both insects and flowers have evolved special structures over a long period of time.

Insect-pollinated flowers are usually brightly coloured and scented. They normally contain sweet liquid called nectar as well as pollen which the insects collect. Some flowers produce extra pollen as insect food, but no nectar. The dogrose is an example. The pollen of insect-pollinated flowers is sticky and adheres to the bodies of insects. Because of the more efficient pollination mechanism less pollen is produced than in the wind-pollinated flowers.

Extremely important pollinating insects are bees. For this reason fruit growers frequently have hives in their orchards to increase the fruit crop through more efficient pollination. In their search for pollen bees visit large numbers of flowers—usually all of the same species at a particular time—and pollinate them. The relatively long tongue or proboscis of bees enables them to find nectar that is concealed, as in petal spurs, for example.

Bees visit purple, blue and yellow flowers but not very frequently red flowers. Experiments have shown that the insects are attracted by colour from a distance and then both by colour and scent when they are close to the flower. The dark lines on petals—so-called honey guides—are believed to guide the insect to the nectar and the stamens and the stigma. Butterflies and moths are also important pollinating agents. Butterflies visit all types of flower, chiefly red and white ones. Their long tongues can reach nectar in very deep flowers.

The self-pollination of a composite. Three stages in the process are shown. The stigma pushes up through a tube formed by the stamens and becomes covered in pollen.

A bee probes for nectar with its long tongue or proboscis extended.

Pollinating rhododendron flowers at Kew gardens. In these gardens, near London, is one of the largest collections of living plants in the world.

(left) Section through a pea flower to show the arrangement of the parts, and (above) a pod opened to show the seeds.

Night-flying moths hover in front of flowers and reach the nectar with their very long tongues. The flowers are usually white or yellow, so that they are easily seen in the dark, and strongly scented (e.g. honeysuckle). Their stamens and stigmas protrude from the flower, touching the hovering moth. Other insects that frequently visit flowers include flies and beetles. They are not specialised for reaching concealed nectar and are normally found on 'open' flowers such as hogweed. Heads of the flowers are frequently covered with insects that feed on exposed nectar. The stamens of individual flowers ripen before the stigmas are ready to receive pollen and the insects transfer pollen from the younger flowers in the centre of the head to the outer older flowers whose stigmas are ripe.

Flowers of the family Compositae (containing the daisies and dandelion) are also visited by various types of insect. Most insect-pollinated flowers employ one of the methods outlined to avoid self-pollination, though in flowers such as daisies before they fade self-pollination takes place. The stigma pushes up through a tube formed by the stamens and becomes covered in pollen.

On reaching the stigmas of a flower the pollen grains may germinate and the male cells within fuse with parts of the ovules. The fertilized ovules mature to form seeds, each containing an embryo or young plant.

The seeds are dispersed by wind, by an explosive mechanism or by animals, and if they reach a suitable site where conditions are favourable the young plant will emerge from the seed to start another life cycle.

Male catkins and red female flowers of hazel are designed to ensure cross-pollination. (below) The cherry flower is insect pollinated.

CHAPTER 17

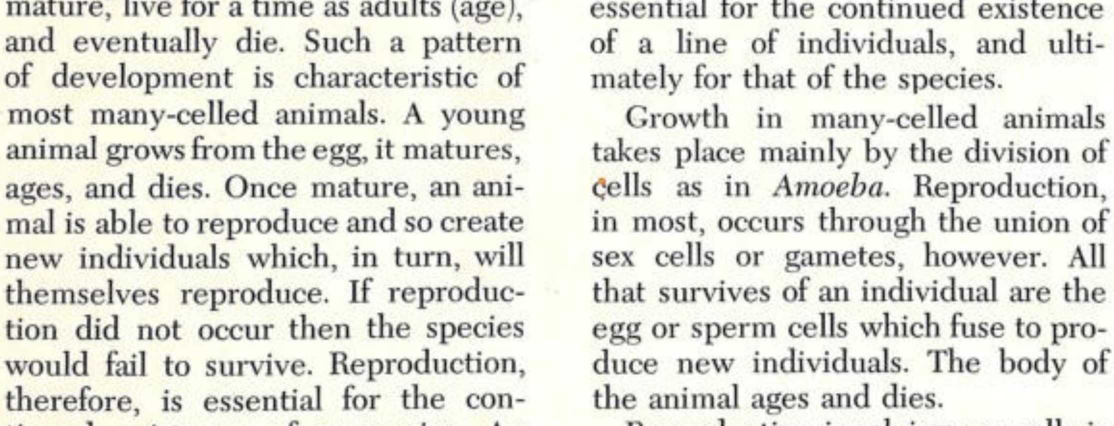
The new generations of animals

A FEMALE frog lays her eggs in water. They are fertilized by sperm from a male frog. Each fertilized egg cell or zygote develops into a tadpole which hatches out several days later. The young tadpoles grow up or mature, live for a time as adults (age), and eventually die. Such a pattern of development is characteristic of most many-celled animals. A young animal grows from the egg, it matures, ages, and dies. Once mature, an animal is able to reproduce and so create new individuals which, in turn, will themselves reproduce. If reproduction did not occur then the species would fail to survive. Reproduction, therefore, is essential for the continued existence of a species. An amoeba, for example, reproduces mainly by a process of division or *binary fission*—splitting into two. No amoeba is able to go on growing and living indefinitely without dividing. The changes that take place prior to and during the division of its nucleus and protoplasm appear essential for the continued existence of a line of individuals, and ultimately for that of the species.

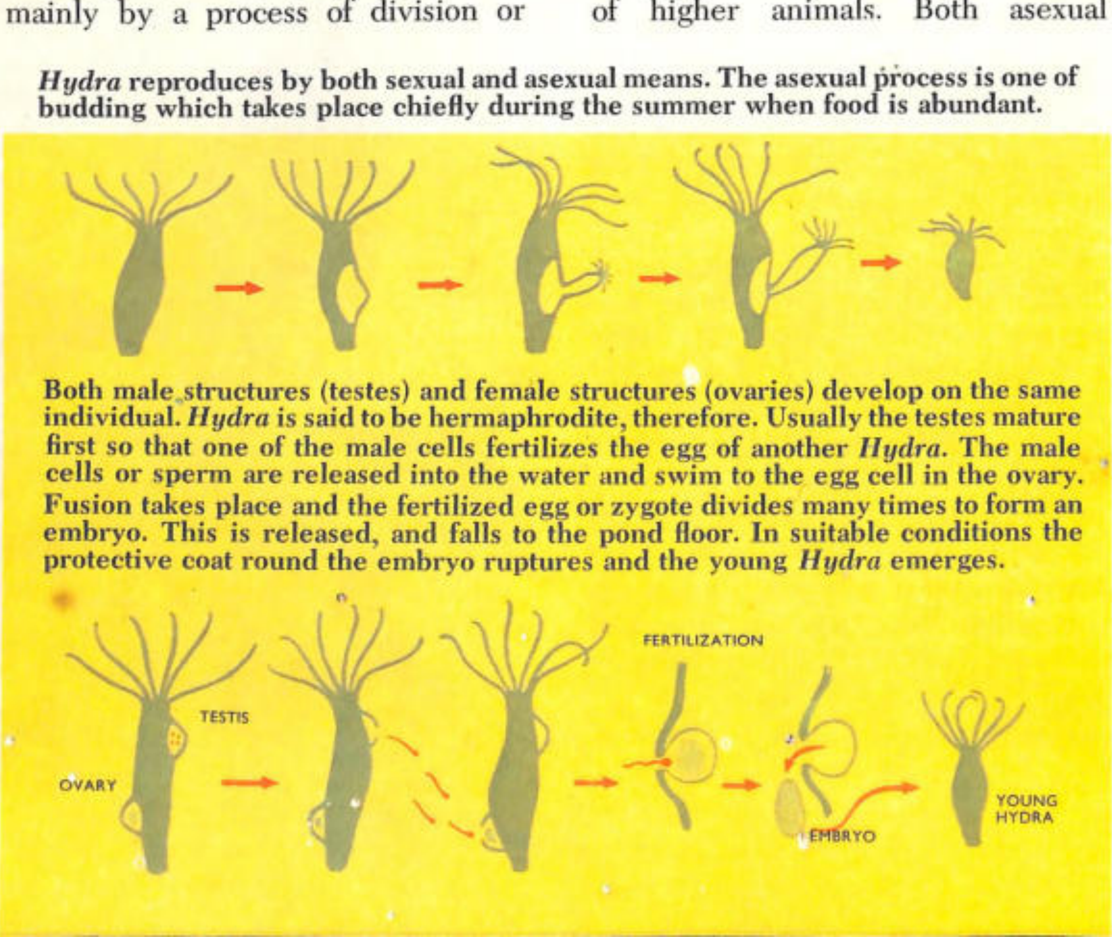
Growth in many-celled animals takes place mainly by the division of cells as in *Amoeba*. Reproduction, in most, occurs through the union of sex cells or gametes, however. All that survives of an individual are the egg or sperm cells which fuse to produce new individuals. The body of the animal ages and dies.

Reproduction involving sex cells is said to be sexual. It is characteristic of higher animals. Both asexual

***Hydra* reproduces by both sexual and asexual means. The asexual process is one of budding which takes place chiefly during the summer when food is abundant.**



Both male structures (testes) and female structures (ovaries) develop on the same individual. *Hydra* is said to be hermaphrodite, therefore. Usually the testes mature first so that one of the male cells fertilizes the egg of another *Hydra*. The male cells or sperm are released into the water and swim to the egg cell in the ovary. Fusion takes place and the fertilized egg or zygote divides many times to form an embryo. This is released, and falls to the pond floor. In suitable conditions the protective coat round the embryo ruptures and the young *Hydra* emerges.



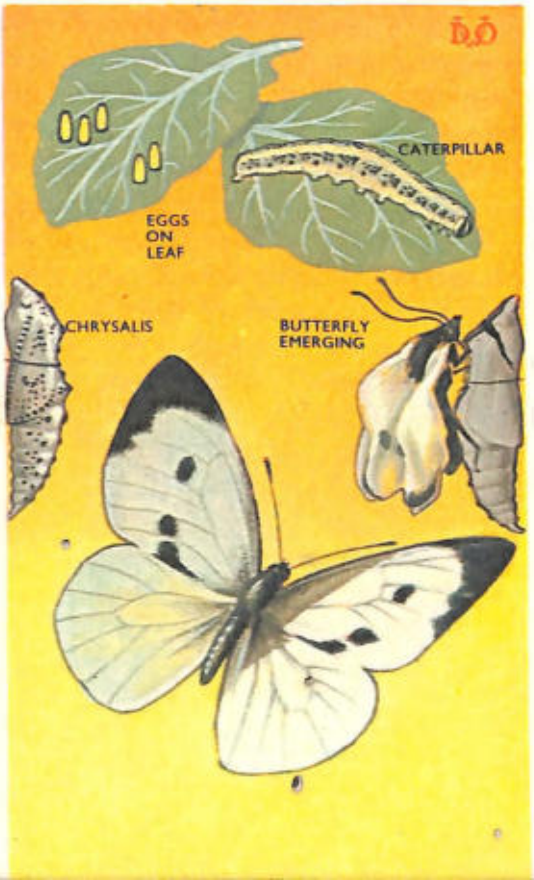
reproduction (without gametes) and sexual reproduction occur in many lower invertebrates (e.g. coelenterates). In the lower many-celled animals, such as Hydra, the protoplasm of many of the body cells seems to retain the capacity for growth and reorganisation. Eventually they form a new adult. In higher animals, only the sex cells retain this ability; the ordinary body cells cannot grow into new individuals.

In some insects (especially greenfly) and roundworms, one or more generations may be produced by the development of eggs that have not been fertilized. This is called parthenogenesis.

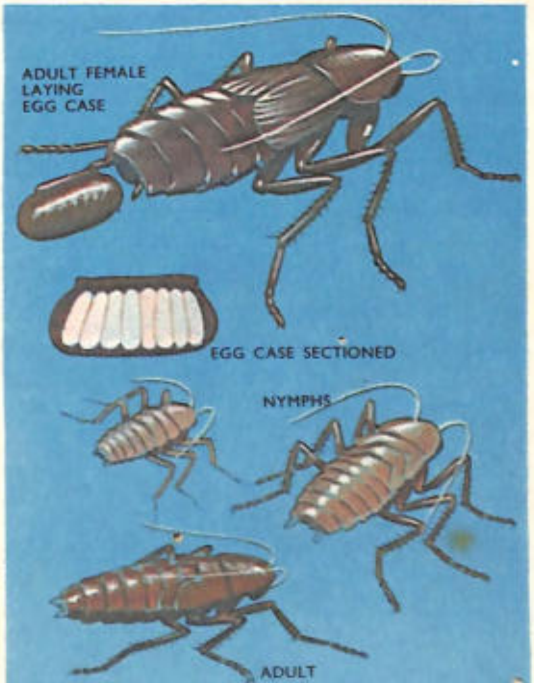
Occasionally the young stage of an animal becomes sexually mature and reproduces, a phenomenon known as neoteny. This occurs in a Mexican newt, *Ambystoma,* for example.

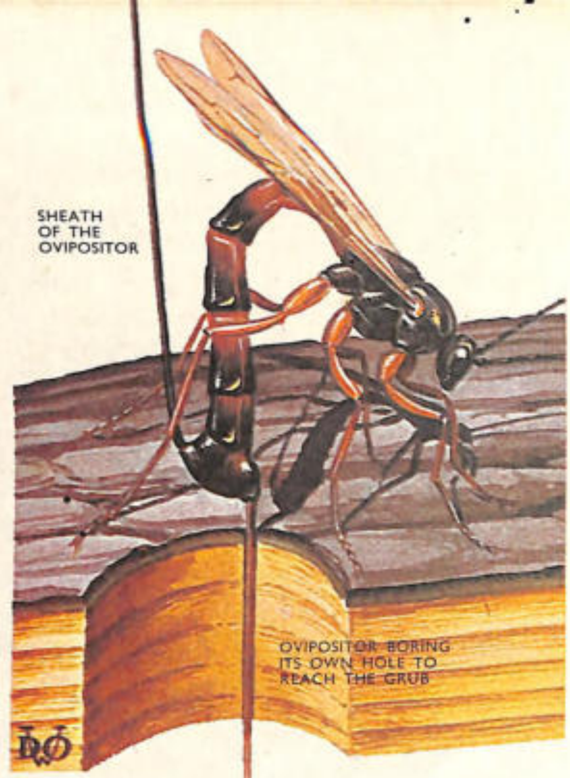
Some animals have a slow, gradual development and when they hatch from the egg or are born alive they appear very much like miniature versions of their parents (e.g. turtles, birds, mammals). Others when they hatch are like their parents but lack certain organs. These larvae, as they are called, develop gradually as they grow up. (An example is the cockroach which, when it hatches from the egg, has no reproductive organs or wings.) Yet others when they hatch are quite unlike their parents in shape or size. The larva changes its form at least once, often several times, before the adult stage of the animal is reached. Each distinct change in form is called a metamorphosis. From a butterfly egg a caterpillar hatches. This eats and grows rapidly before changing into a resting, non-eating stage called a

Life cycle of the cabbage white butterfly.

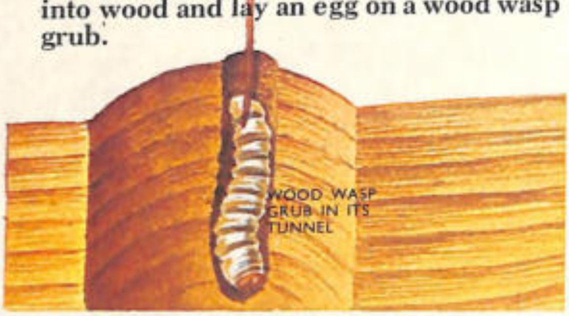


Life cycle of the cockroach.





The ichneumon fly—*Rhyssa*—has a very long egg-placer with which it can bore into wood and lay an egg on a wood wasp grub.



pupa or chrysalis. From the chrysalis the adult butterfly emerges. A crab, prawn or lobster, too, hatches from the egg as a minute, transparent larva which is quite unlike its parents. It may change in form as many as five times while it develops into the adult. Animals such as crabs and insects have a hard outer shell. This restricts growth so, at intervals, it has to be shed. Before the new skin hardens growth in size is rapid.

A striking change in form occurs in the development of a flatfish. The young larva looks very similar to other bony fish larvae with an eye on either side of its head. It spends its time near the surface. As it grows, however, instead of maintaining a herring-like form the whole of its head becomes twisted to one side and both eyes come to lie on one side of the body. The fish then moves to the bottom of the sea where it swims about with the side which has both eyes on it facing upwards.

The larva is often suited to a very different life from the one which its parents lead. A sea urchin lives on the sea floor; its larva, however, is a small, transparent creature equipped with bands of hair-like cilia which beat enabling it to swim about near the sea surface. The dragonfly larva or nymph lives in water and is a voracious feeder with a fierce pair of jaws. The adult, on the other hand, is a fast flyer with two pairs of delicate, transparent wings. It captures its prey while flying, holding it with its front legs.

A female mayfly lays her eggs on the surface of the water or underwater, often placing them under stones. After about ten days a larva, called a nymph, hatches from each egg. The nymph feeds on pieces of plant food, though some species are meat-eaters, and breathes oxygen that is dissolved in the water. Each passes through four stages in its development and during each stage moults many times. At the end of the third stage the nymph comes to the surface, moults, and flies into the air. This stage lasts for a very short time and during a final moult the adult insect emerges.

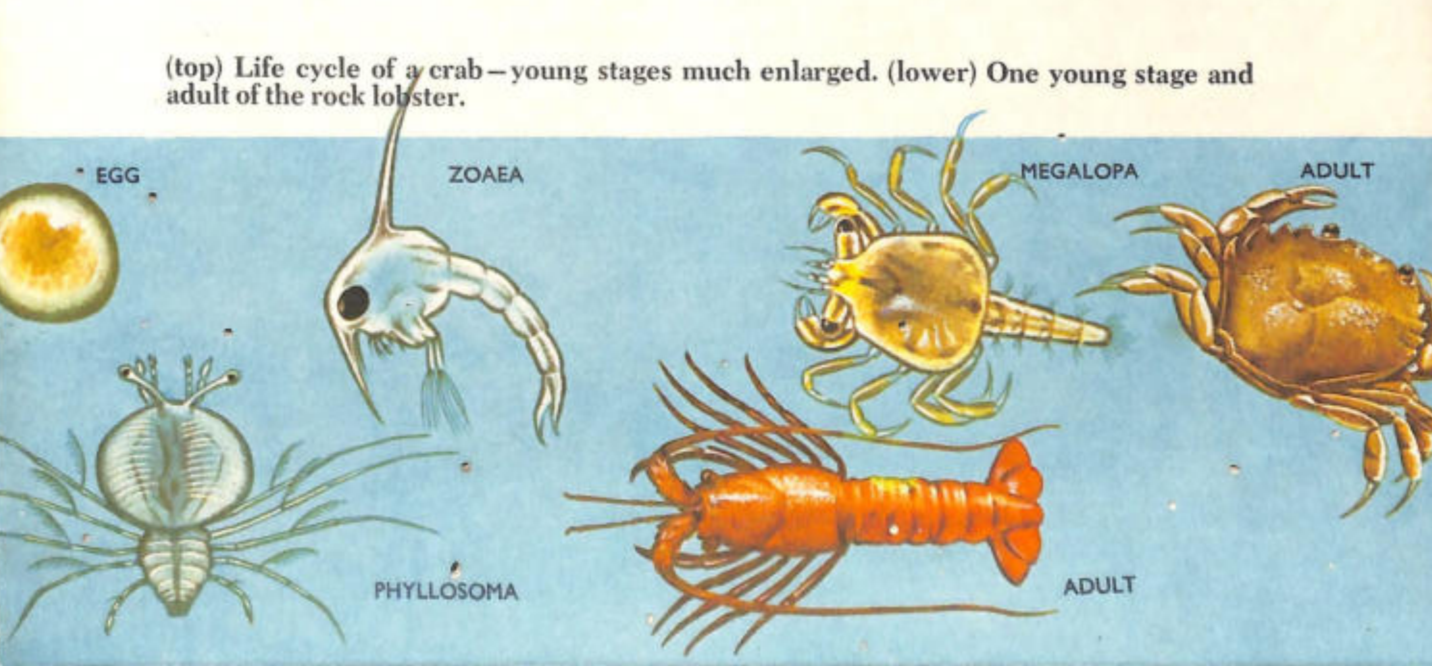
If all the eggs that fishes lay were to survive, the sea would be packed jam-tight with fishes. A female cod may contain as many as nine million eggs, halibut more than two million, tench hundreds of thousands and herring thirty to fifty thousand. Of course, the sea could not support such a population. Many of the eggs are eaten by fishes, often by fishes of the same species, and many are not even fertilized. The chances of an egg or of a young fish surviving are very low so that the production of so many eggs is necessary for the numbers to be maintained.

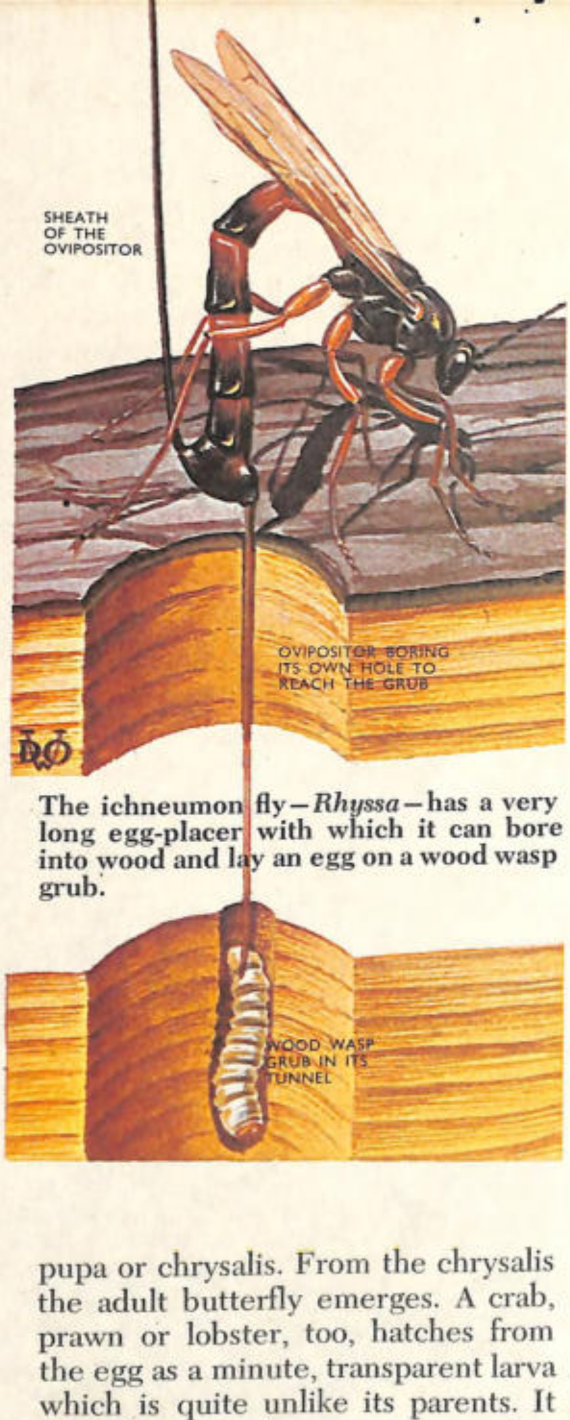
Not all fishes produce as many eggs as those quoted above. As a general rule, the numbers depend on the degree of care that the eggs and young receive from the parent fishes. Female sticklebacks lay from fifty to a hundred eggs only, in an elaborate nest.

The reproductive habits of fishes vary enormously. Many, such as herring and mackerel, assemble in vast shoals, prior to spawning, whilst others (e.g. salmon) form pairs. The act of pairing may be preceded by an elaborate courtship display, prior to which the male often becomes brilliantly coloured. A female salmon lays her eggs in a hollow which she has 'cut' with her tail in the gravel beds. The male sheds his sperms over the eggs after they have been laid. Some fishes perform extensive spawning migrations. Salmon return to freshwater from the sea while European and North American eels make their journeys in the reverse direction, travelling from freshwater lakes and rivers across the Atlantic to the Sargasso sea.

In sharks (and a few bony fishes) fertilization is internal, the sperms being guided into the female by a pair of claspers – modifications of the paired pelvic fins. Many sharks (e.g. dogfish) and most rays and skates, produce large horny egg cases – so called 'mermaid's purses' – each of which contains a large yolky egg. The purses are laid in the water and become attached to seaweeds by means of their long coiled filaments. The embryos develop within them and are nourished by the rich supply of yolk. Many shark-like fishes bear their young alive, however (so do a few bony fishes, for example, guppies, surf fishes and live-bearers). The spur dog carries as many as eleven young (four on average) and female tope have been found with over thirty inside them. In the smooth hound the yolk sacs of the young are richly supplied with blood vessels. Finger-like projections from the wall of part of the reproductive

(top) Life cycle of a crab – young stages much enlarged. (lower) One young stage and adult of the rock lobster.





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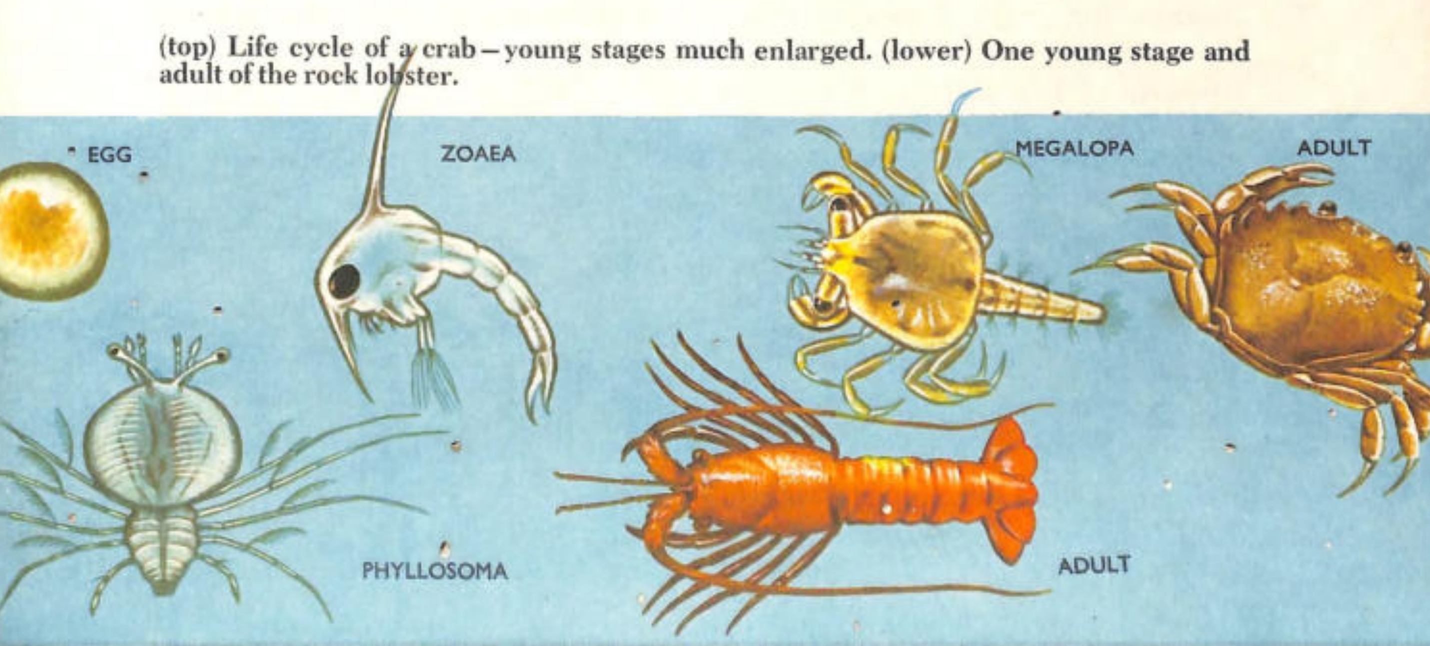


system fit closely into pits in the yolk sacs. Such an arrangement is similar to that found in mammals, where the womb lining grows to form a *placenta* with a very rich blood supply and through which the developing young are nourished. Somewhat similar arrangements are also found in a few bony fishes.

The eggs of the salmon are heavy and sticky and become attached to stones. Those of the turbot and shad are also heavy and sink to the bottom, where they may drift and roll about in the currents. Herring also lay eggs that sink, but most other commercially important fish, for example cod, pilchards, mackerel and plaice, lay floating eggs. These contain droplets of oil which make them buoyant.

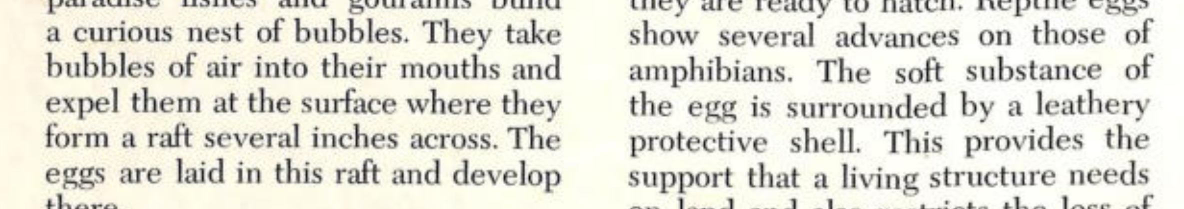
Male seahorses have a special brood pouch under the abdomen. The eggs develop in this pouch. Most of the paradise fishes and gouramis build a curious nest of bubbles. They take bubbles of air into their mouths and expel them at the surface where they form a raft several inches across. The eggs are laid in this raft and develop there.

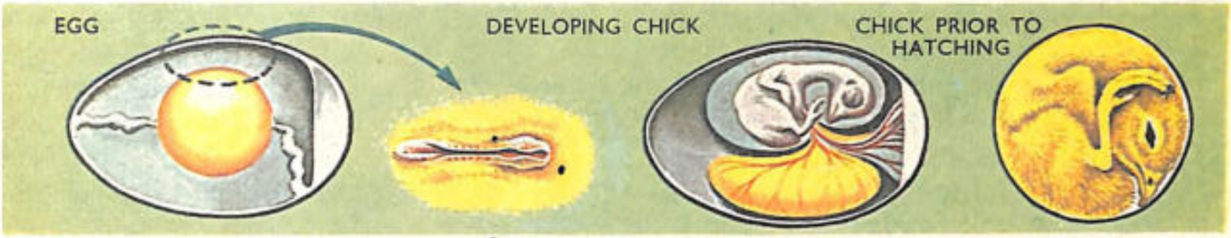
The bitterling is a fish that has an extraordinary association with certain freshwater molluscs – the mussel, *Unio*, and the swan mussel, *Anodonta*. The female bitterling has a long egg tube, the ovipositor, which she inserts into the inhalent siphon of the mollusc. The eggs are carried within the latter's shell by the ingoing water current. The sperms of the highly coloured male fish also enter by this route and fertilization takes place inside the shell.

Most amphibians have to return to water to breed. Their eggs are soft and jelly-like, lack a supporting shell, and the young, which breathe by means of gills, can live only in water. But whereas amphibians have met with only moderate success in their efforts to colonise land, reptiles have succeeded – to such an extent, in fact, that present day water-dwellers (e.g. turtles) have to return to land in order to breed!

Most reptiles lay eggs, some give birth to live young and a few retain the eggs within their bodies until they are ready to hatch. Reptile eggs show several advances on those of amphibians. The soft substance of the egg is surrounded by a leathery protective shell. This provides the support that a living structure needs on land and also restricts the loss of water to the atmosphere. The eggs are supplied with large quantities of yolk to nourish the developing young, and a special sac, the *allantois*, enables oxygen and carbon dioxide

Development of a flatfish showing how it loses the typical fish appearance.





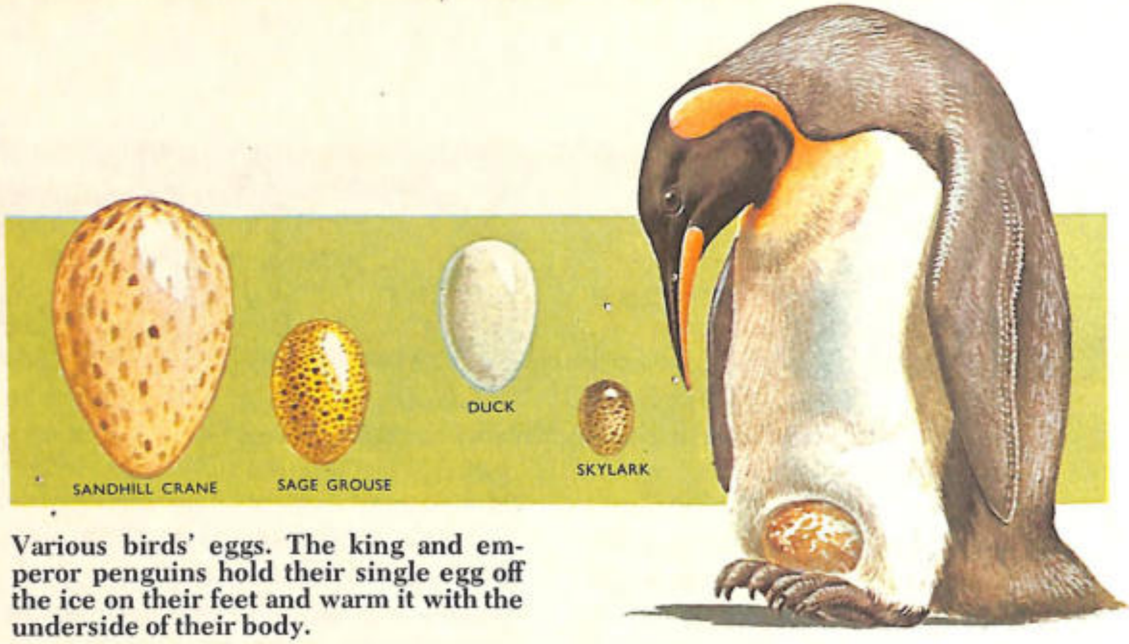
Development of a chick embryo within the egg.

to pass between the embryo and the outside world. Each embryo develops in a fluid-filled sac or amniotic cavity, the equivalent of the frog tadpole's pond.

Except in lizards, there is usually little difference in the appearance of male and female reptiles of the same species. Amongst the crocodiles, for example the American alligator, the difference is merely one of size. The male is often larger and heavier than the female after about the sixth year. Amongst turtles there are rarely differences in colour and often not in size, but when there are size differences the female is usually the larger, though the male has a relatively larger tail. In snakes the two sexes are very much alike, and the production of scent by special glands apparently serves as a means of recognition. It is among lizards, however, that striking sexual differences, approaching those of some fishes, are to be found. They may be permanent structural features, or momentary or seasonal changes in appearance. A male Owen's chameleon has three large pointed horns on its head, whereas the female has one only; these are permanent features, as are the vivid colours of the throat and underside of male spiny lizards. Male agamids and iguanids are well known for their ability to become momentarily brightly coloured. In the breeding season the male collared lizard takes on striking colours. At this time male lizards also defend their territories ferociously, driving away male intruders by means of violent attacks.

Since reptiles produce eggs that have shells, fertilization must be internal and takes place high up in the reproductive system, beyond the shell-producing glands. Some means of introducing the sperm is also necessary and male reptiles have well developed structures serving this purpose.

All crocodiles and turtles lay eggs, so far as is known. The majority of snakes and lizards also lay eggs, but others give birth to live young. The viviparous lizard is remarkable in that it normally produces live young, yet over part of its range—in the Pyrenees—it lays eggs. Amongst egg-

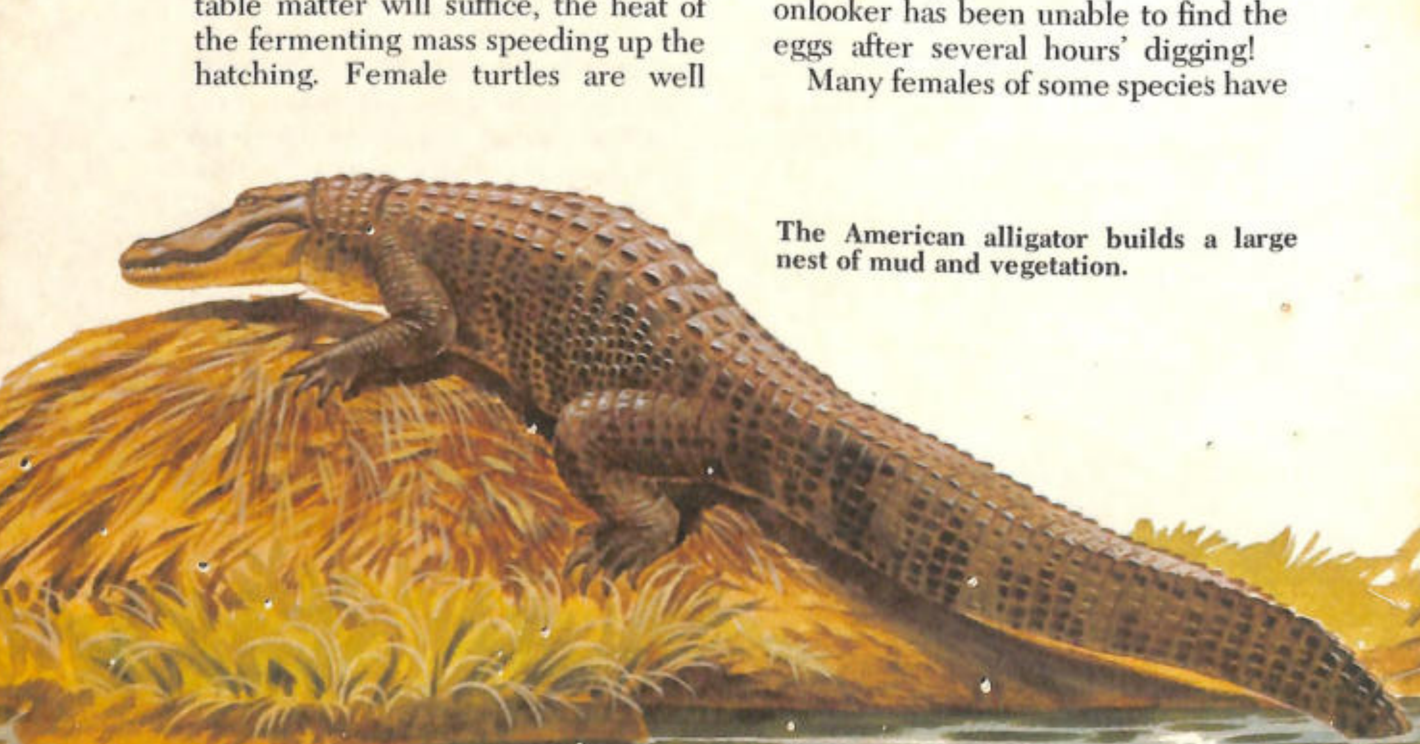


Various birds' eggs. The king and emperor penguins hold their single egg off the ice on their feet and warm it with the underside of their body.

laying reptiles the number of eggs laid varies from one to over a hundred. The monitor lizards and horned toads may lay thirty or more, but most lizards lay fifteen or less. Geckos and iguanids often lay a solitary egg. Snakes (particularly pythons) and turtles are the most prolific, some snakes laying over a hundred eggs and some sea turtles producing two hundred.

Nest building is rarely very elaborate, and more often than not a hole in the ground or a pile of waste vegetable matter will suffice, the heat of the fermenting mass speeding up the hatching. Female turtles are well known for their habit of returning to land in order to lay their eggs – often, it seems, to the same sandy beach, and the one on which they themselves hatched. Whereas some turtles deposit their eggs in a shallow depression and hardly bother to conceal them, others take great pains, first digging a deep hole with their flippers, before depositing the eggs. Sand is then thrown over them until they are buried and the site of the nest is concealed by more loose sand. This process may be so effective that an onlooker has been unable to find the eggs after several hours' digging!

Many females of some species have



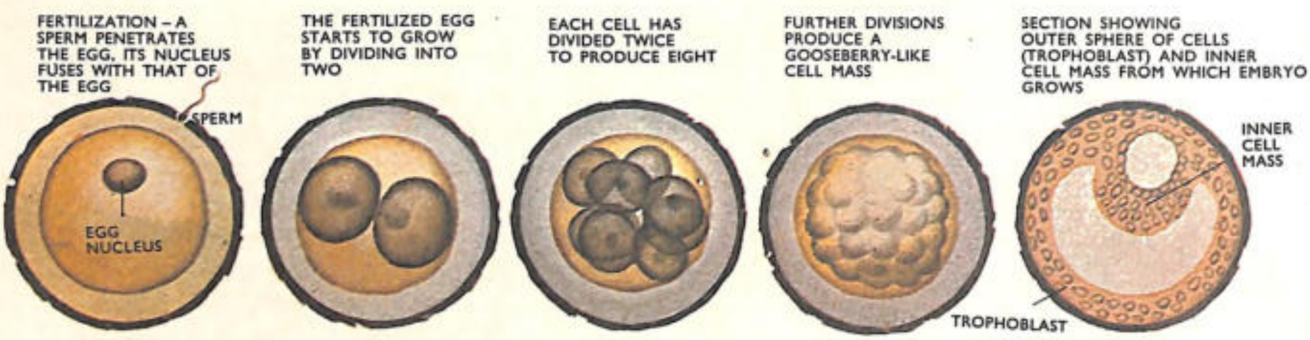
The American alligator builds a large nest of mud and vegetation.

the habit of congregating in one place, to lay. The European grass snake is famous for this habit and sometimes several thousand eggs are found together. This snake, like many others, lays its eggs where there is an abundance of rotting plant material, the heat of the fermenting mass increasing their rate of development.

The female American alligator constructs a large nest as much as seven feet across and three feet high. The nest is a mound constructed of decaying plants, freshly collected leaves and other vegetable matter. A hollow in the centre is scooped out and lined with mud and water plants. She deposits her eggs (approximately thirty to seventy in number), turning round in the hollow as she lays, and covers them with mud and vegetable matter. The whole of the nest is then smoothed over by the great body of the alligator. The nest is carefully guarded and even watered during dry weather. Incubation takes about nine weeks. Sounds from the young, prior to hatching, provide the signal for the female to bite the top off the nest so that they may escape.

Birds are highly industrious creatures. From dawn until dusk their continuous activity can be witnessed. Their reproductive and associated behaviour is particularly intense and noticeable. Many birds undertake long migratory flights in order to reach their breeding grounds, and

The peacock puts on a display with his huge tail fan to attract a mate.

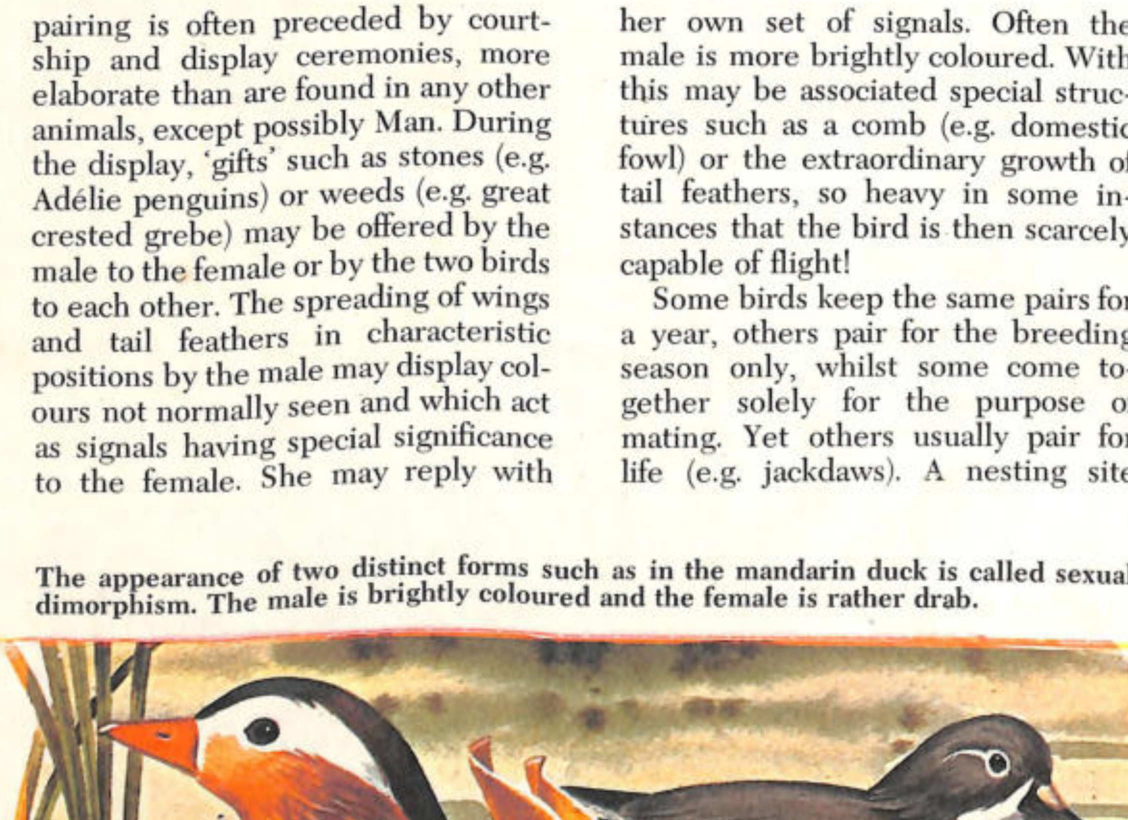


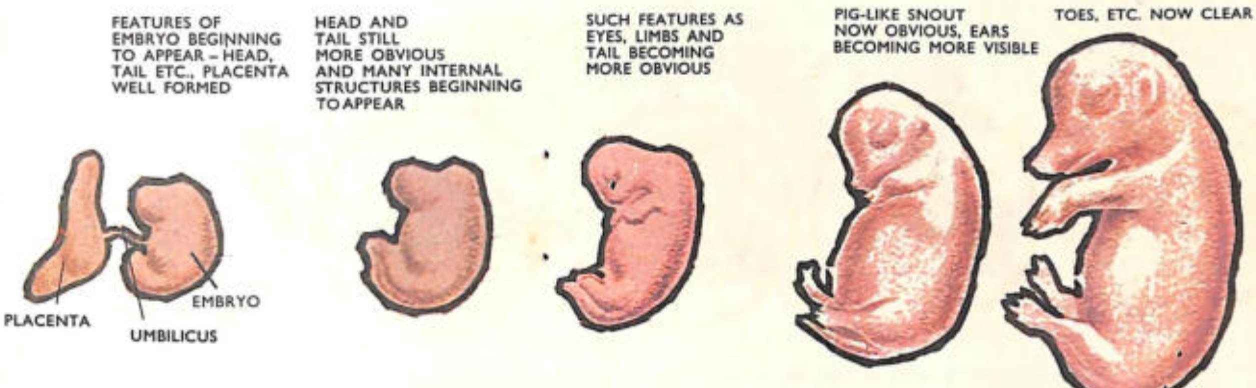
Several Stages in the Early Development of the Pig.

pairing is often preceded by courtship and display ceremonies, more elaborate than are found in any other animals, except possibly Man. During the display, 'gifts' such as stones (e.g. Adélie penguins) or weeds (e.g. great crested grebe) may be offered by the male to the female or by the two birds to each other. The spreading of wings and tail feathers in characteristic positions by the male may display colours not normally seen and which act as signals having special significance to the female. She may reply with her own set of signals. Often the male is more brightly coloured. With this may be associated special structures such as a comb (e.g. domestic fowl) or the extraordinary growth of tail feathers, so heavy in some instances that the bird is then scarcely capable of flight!

Some birds keep the same pairs for a year, others pair for the breeding season only, whilst some come together solely for the purpose of mating. Yet others usually pair for life (e.g. jackdaws). A nesting site

The appearance of two distinct forms such as in the mandarin duck is called sexual dimorphism. The male is brightly coloured and the female is rather drab.





EMBRYO OF ABOUT SIX WEEKS

may be found before or after pairing. Trees, hollow cavities in walls, pipes, cliff-ledges, and hollow depressions in the ground or in a tree branch are amongst the variety of nesting places (see chapter 18).

The eggs are generally oval in shape with one end blunter than the other. Birds are not as prolific as reptiles, though the number of eggs varies from species to species and between separate clutches of the same species. Four to six is a normal clutch for most of the perching birds (robin, sparrow, rook, etc.), and many others. The golden eagle lays two eggs. Pheasants and partridges may lay up to fifteen.

Whereas reptile eggs are usually a dirty white or cream colour, those of many birds are beautifully marked, often blending remarkably with the background. The Ringed Plover constructs no nest—its eggs are laid among pebbles and stones which they match so closely that they are difficult to see. The eggs of many birds are white, however (e.g. wryneck, owls, petrels, swift), whilst in others the eggs are brightly speckled. Possibly their colour helps to maintain the broody state of the parents, for experiments in which eggs of the wrong colours have been placed in the nest resulted in the broody bird leaving.

Each egg has a rich supply of yolk for the developing embryo, though the proportion is not as high as in reptiles (e.g. turtles)—presumably this is related to their more rapid development. Birds, like mammals, are warm-blooded and the developing egg must be kept warm. This is performed by one or both of the parents (usually the female) who incubates them while 'sitting on the nest'. Special bare patches of skin—the brood patches—are well supplied with blood and they are applied closely to the eggs. King and emperor penguins have a unique way of incubating their eggs, holding them off the ice or the cold ground with their feet.

Mammals, such as the cat, look after their young for a long period after birth.

The only birds that do not incubate their eggs with heat from their own bodies (apart from a parasite such as the cuckoo) are the mound builders or *Megapodes*. Famous amongst these is the Australian brush turkey which builds enormous mounds from scraps of vegetation, the heat from the fermenting mass incubating the eggs. The temperature of the mound is carefully controlled by the male bird who adds material to increase it or digs holes in it to cool it down, as necessary.

The pouched mammals or marsupials differ from the highest group of mammals (placentals) in a striking way. The young are born at a very early stage in their development—in the opossum from only eight to thirteen days after fertilization has occurred. They then crawl to a pouch on the abdomen of the female where they spend the early part of their lives, being suckled on milk from the mammary glands.

The kangaroo is probably the best known marsupial. Others include the wombat, koala, native cat, Tasmanian devil, wallaby and the banded anteater.

Not all marsupials have a pouch or marsupium as well developed as that of the kangaroo. Some merely have two flaps of skin whilst others, for example the woolly opossum, have no pouch. In this case the youngsters hang on to the nipples of the female as she moves around.

In the placental mammals (e.g. rabbit) the developing embryo obtains its nourishment from the mother by way of a placenta—a specialised organ formed by the union of the womb lining and certain embryonic tissues. Such a device permits a long period of development and consequently the young are well developed at birth. In marsupials, however, the young are not nourished by a placenta, except in the bandicoot, but even here the placenta is relatively simple in structure. As embryos, the only nourishment they have is the store of yolky material in the egg and a supply of 'milk' from the womb *(uterus)* lining. The yolk is quickly exhausted and consequently the young are born at an immature stage. They have to reach the pouch where, clinging to the nipples with their mouths, they can obtain the nourishment required for their further development.

At birth, the offspring of the Virginia opossum are no larger than a honey bee. Even those of the great grey kangaroo are merely an inch or so long and weigh only an ounce.

CHAPTER 18

Constructing a home

Not all animals construct a shelter to hide, sleep or reproduce in. Many of the hoofed grazing animals, for example, are 'nomads' wandering around permanently. But many animals do build themselves a home and this is often an exceedingly elaborate structure. Generally speaking the more complicated that it is the greater the use that is made of it. Simple homes may be no more than places in which to hide from enemies or in which to keep a lookout for prey. On the other hand the remarkable structures built by beavers serve as a home in all senses of the word; somewhere to sleep, somewhere to hide from enemies, a place to have young and to rear them, and a place to engage in all the other activities of living.

Beavers are the animal engineers supreme. No other animals construct on the same scale. These creatures, some three feet long, and weighing about forty pounds, are able to build

Beavers are the animal engineers supreme. The picture shows a group of beavers collecting branches in order to strengthen the dam retaining the water of their pond. The lodge is the large domed structure in the centre of the picture.

The beavers work in an area where there are ample supplies of the trees from which they eat the bark. These include poplar, aspen, cotton-wood, and willow. Their tools are four sharp orange-yellow front teeth which are able to chisel through trees several feet in circumference.

The lodge is constructed in such a way that even when the pond is frozen over in winter, the beavers are able to come and go underwater safe from attack by their enemies.

dams up to a hundred yards long and twelve feet high. They fell trees several feet in circumference, construct canals a fifth of a mile or more long along which they float logs and branches, and build elaborate 'air-conditioned' houses with underwater entrances. They may also dig into the banks of streams forming intricate networks of tunnels many feet long.

The beaver's tools are four sharp, orange-yellow front teeth, used as chisels, and the fore feet are equipped with sharp, tough claws and used for burrowing. The toes of the fore feet are not webbed and can be used in a similar manner to our fingers to grasp logs and branches. They are their trowels as well, for the beavers spend much of their time stopping up gaps in the dam and cementing branches together with mud.

The dam is built across a stream to form a pond for the house or lodge site. The beavers work above the dam which is constructed of logs, branches, stones and mud, in an area where there are ample supplies of the trees from which they eat the bark. These include willow, poplar, aspen and cotton-wood.

The lodge may be built on the edge of the pond or on a natural small island. Sometimes it is built around a small, bushy tree. It is a domed structure made of piled-up branches cemented together with mud. Often it rests on a foundation of boughs and mud which may itself rest on a layer

This tiny American humming bird (left) makes its nest of seed fibres and spiders' webs. (right) This Australian flowerpecker builds its nest high up in a tree.

of peat and moss. Only the branches making up the walls are cemented together; the domed roof consists of uncemented branches so that the hollow chamber within is properly ventilated, even in the depth of winter. The floor of the chamber is always a little above the level of the pond and may be stepped so that the sleeping quarters are above the wet openings of the entrance and exit tunnels. They provide access to the underwater store of branches and to the rest of the pond. The tunnels go underground for a short distance, opening underwater into the pond.

In felling a tree the beaver props itself up on its tail, with its hind legs spread apart and the claws of the forefeet grasping the trunk. The front teeth gnaw their way through the bark into the wood. Large chunks are torn out until eventually the tree falls over. The beaver does not control the direction of the fall by cutting on a particular side, for beavers have been killed by falling trees. The trunk is cut into shorter lengths—five feet or so, the length depending on the distance that the logs have to be moved—and the logs are dragged to the water and floated downstream to the site of the dam. The logs and branches are cut green and so they sink readily. They are weighted down with stones and mud, being laid parallel to the flow of the stream, though the current may still disturb them. The finished dam holds back the water so that it is sufficiently deep for the beaver to enter its lodge and reach its underwater food store in the winter when the pond is frozen over. A gap ensures that excess water flows away out of the pool so that its level stays the same. Several dams may be built downstream of the lodge and one or more may be built upstream. The pond is the beaver's sanctuary, a moat surrounding his island fortress, the lodge.

Nest-building is an activity that is characteristic of birds, though not

The yellow-throated scrub wren of Australia builds its nest at the tips of hanging branches.

The Baltimore oriole builds a hanging nest about six inches deep.

all birds build them. Material for the nest may be obtained from the immediate surroundings of the nesting site or it may be brought from considerable distances. Swallows will collect mud several hundred yards from the nest, whereas a swan uses grass, water-plants etc., that are close at hand. The nest may be constructed by one or both birds of a pair and the same nesting site may be used several years running, new material being added on top of the old nest, so that eventually a nest of massive size is produced. Such are the nests of herons. Owls and falcons make no nest but use tree hollows or merely scrape a hollow depression in a ledge or somewhere similar. They may also take over the old nests of other birds. The social weavers of South Africa build enormous communal nests, and as many as three hundred pairs may live in the same 'apartment house'.

Common building materials are twigs, leaves, dry grass, moss, lichens, mud and feathers. In many instances the nest consists of an outer layer of coarse material—twigs, sticks, straw and the like—while the inner lining is of a finer, softer nature—hair, wool, feathers etc. Usually the bird uses its bill to fix building materials in place whilst the actual shaping of the nest is done with the feet, wings and body. A few birds, such as the weavers, many of which build hanging nests made of grass and palm fibres, actually tie the strands into knots.

Most kingfishers make burrows in the banks of streams, a few in termite mounds and similar situations. They dig the burrow with their sturdy beaks and use their joined toes to scoop the earth out. The tunnel ends in a hollow rounded chamber and the eggs are laid on bare earth. No nesting material is used. Woodpeckers burrow into tree trunks and branches, drilling a horizontal hole a few inches deep and then a vertical tunnel a foot or so down into the trunk. Like kingfishers they use no nesting material, other than a few wood shavings.

The tailor bird of India and South-east Asia has the remarkable habit of sewing the edges of one or two leaves together, using as thread plant fibres or the silk from insect cocoons or spiders' webs. The hollow cup so made is then lined with grasses, hairs and any other handy soft materials.

The bower birds of northern Australia and New Guinea build more elaborate structures than any other birds. But strangely enough these are not nests but courtship devices constructed by the males in order to procure females for breeding purposes. In one instance the bower reaches a height of nine feet. The walls may be decorated with flowers, mosses and ferns.

Perhaps the best known of all burrowing animals is the common mole of Europe. The nest itself is placed under a large mound often concealed near a low growing bush, such as bramble. It is a deep structure forming a central chamber around which there are often roughly circular galleries with branch hunting tunnels leading off.

The circular tunnels whose walls are smooth are used by the mole to pass to its hunting grounds. The hunting tunnels are dug out frequently and the excavated earth is pushed above ground as the molehills with which most people are familiar.

Badgers are other animals well known for their burrowing activities. It seems likely that a young burrow is a simple affair with an entrance hole leading along a short tunnel to

The nesting chamber of the common mole is usually constructed under a large mound. The bedding consists of dry grass and leaves. Leading off from this central gallery are other tunnels used by the mole on its hunting sorties.

The nesting burrow of the badger is usually short with the nesting chamber at the end. Over a period of time other tunnels may be excavated out leading from this.

an enlarged chamber. However, badgers are communal creatures and they inhabit the same network of burrows for several generations so that ultimately the tunnel network becomes extremely complicated. Often there are several entrances with tunnels extending as far as one hundred yards in an exceptional case. So extensive may the network become that often other creatures such as rabbits and foxes will inhabit parts of it. The sets can be found in all types of country and badgers seem to dig them in all types of soil. By far the most common habitat is woodland, especially where water is nearby and where the land slopes. Some sets constructed in hillsides are often two or three storeys deep, with one layer of tunnels above another. In England it seems likely that the parent badgers pair in July and the young are born in the set the following February. There is variation in this 'schedule' – young may be born in January in

The nest of the kingfisher is commonly in the bank of a stream at the end of a narrow tunnel several feet long. No nesting material is placed in it, the eggs are laid on bare earth. ▶

which case mating will have taken place sooner than July—but this is the typical pattern. The living quarters of the set are lined extensively with bedding which consists of dry grass, leaves and similar materials. Badgers are very clean creatures, for quantities of used bedding are to be found regularly outside the set.

Many desert animals burrow in order to escape the hot sun of the daytime. So they remain cool during the day and venture forth at night after food when the temperature has dropped considerably. The extraordinary thing about these underground burrows is the constancy of the conditions inside them. During the daytime the temperature of the burrow remains well below that of the air above, and at night it is above that of the air. At the same time the dampness of the air within the burrow is above that of the air above ground so that living conditions are much more tolerable.

Some rodents construct their nests above ground. A master at nest construction is the harvest mouse which makes a ball-shaped nest of interlaced grass leaves supported on the stems of other grasses. No opening is left in the nest, the female merely pushes her way in each time she returns to the nest. The nest is only used for rearing the young, for

◀ **The nest of the harvest mouse is roughly spherical and made of grass supported on the stems of grasses round about. It is here shown cut away to show the young within. No entrance is left in the nest, the female has to push her way in through the wall each time she enters.**

harvest mice live in holes in the ground for the rest of the time.

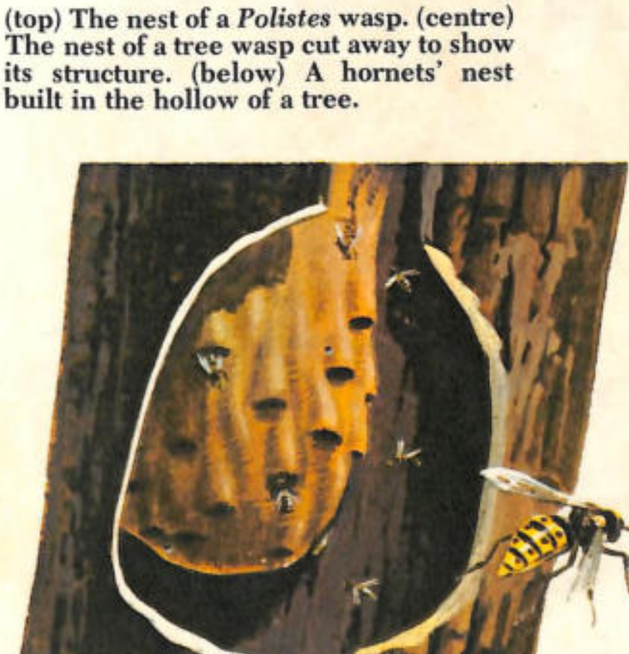
There are several kinds of tree squirrel that build nests. These are usually globular structures placed in the fork of a tree or sometimes in old woodpecker holes, tree hollows or similar places. The red squirrel often constructs more than one nest. An outer layer of twigs is lined with moss, lichens or small pieces of bark. Occasionally even an old crow's nest will be appropriated.

Many insects build nests. Their design and structure is often very complicated. The nests of some ants, wasps and bees may contain many thousands of individuals. Wasps use a variety of materials for nest-building. The potter wasp, for example, constructs vase-shaped nests of soil; others commonly make their cells of wood pulp that has been produced from dead trees and other wooden structures by the rasping action of the tough mouthparts.

A bee, *Prosopis,* makes tiny cells in a reed stem; honey bees build the cells of the comb from wax that they produce in special wax glands. The wax is produced as tiny scales and it is kneaded and fashioned by the mouthparts.

Termites are serious pests of timber. They build their nests in trees or underground. When working with soil they produce a very hard structure by mixing the soil with saliva to form a sort of cement which hardens as it dries out. Some termite mounds are enormous structures many feet high and when many of them occur together the landscape takes on the appearance of some ancient temple constructed albeit in a rather haphazard fashion from the point of view of symmetry.

(top) The nest of a *Polistes* wasp. (centre) The nest of a tree wasp cut away to show its structure. (below) A hornets' nest built in the hollow of a tree.



Which animals look after their young?

EXCEPT in birds and mammals of the backboned animals and some social insects amongst animals without backbones, care of the young by the parents is usually non-existent. There are exceptions, however.

Amongst fishes, for example, female sticklebacks lay from fifty to a hundred eggs only, in an elaborate nest usually constructed of seaweed in marine species or algal threads and water weeds in freshwater species. The nest is built by the male and he zealously guards it and its immediate surroundings from intruders. Even when the eggs hatch he guards the young just as carefully until they are able to fend for themselves.

In the African lakefish—*Tilapia*—the female usually incubates the eggs and guards them in her mouth. Even for a time after the young have hatched they are taken back into her mouth when danger threatens. They are protected in this way for almost a week.

Many egg-laying snakes guard their eggs by remaining curled around them. Some put up a vigorous defence against intruders. It is thought

A female sea otter swims on her back while supporting a young otter on her abdomen. Young otters do not take to the water readily at first.

Most monkeys live in trees in which they are expert climbers. The young are commonly carried in this position clinging tightly to the mother.

The Australian brush turkey builds an enormous mound from scraps of vegetation. Heat from the fermenting mass incubates the eggs.

Kangaroos belong to the group of mammals with pouches. The young are born at a very immature state and then spend some time in the pouch feeding on milk produced by mammary glands. The young do not leave the pouch of the red kangaroo until they are eight months old. They continue to use the pouch for some time after this.

that male and female cobras take it in turns to guard the eggs, and one species of python is actually thought to incubate its eggs. However, parental care in snakes goes little beyond defence of the eggs, for the parents leave the young to fend for themselves after hatching.

Parental care reaches an extremely high level in birds. Not only are the eggs incubated by the adults, but the young, of necessity, are provisioned and cared for as well. The young break out of their shells by means of an egg tooth or caruncle on top of the bill. They are kept warm by heat from their parents' bodies. In some instances—ducks, geese, turkeys—the chicks are able to run actively and peck for food a day or two after hatching, but, generally speaking, they are helpless and quite dependent on the parents.

The adult birds spend a large part of each day collecting insects and their larvae, worms, and other suitable food—fish in the case of sea birds—for the nestlings. Adult pigeons produce a curd-like milk in their crops with which to feed the young. Nestlings may consume their own weight of food each day. It seems that the noise they make on the return of the parents to the nest, and the bright colours of the insides of their mouths, stimulate the parents to feed them. The shape of the parent's head is also a stimulus to the young birds. Besides providing food, the adult birds also clean the nest, removing faeces and other unwanted material. They will also feign injury or walk away from the nest in an attempt to distract the attentions of an intruder or a would-be predator from the nestlings.

Grebes are noted for the habit of carrying their fluffy young about on their backs or tucked under their wing or long back feathers. They

This robin has made its nest in an old flowerpot. Robins, like other birds, exercise a high degree of parental care and much of their time is spent bringing food to the young nestlings.

Lions are very affectionate creatures. The young have spots like their cousins the leopards until they are much older. The lioness teaches the youngsters to hunt. At first they are very clumsy but their efficiency soon improves.

even dive under water with the young still aboard and if dislodged the young come bobbing up to the surface waiting to be picked up again.

Parental care probably reaches its highest level amongst the mammals. As their name suggests, mammals are animals that are suckled on milk produced by special glands called mammary glands. It is not known in many instances how long the young are suckled. Many small rodents take milk for only ten days or so but the walrus, at the other extreme, is known to suckle its young for two years.

Usually it is the mother that looks after the young and they may remain in her care for a period of from a few weeks to many months. Often, however, the male parent takes an active part in the care of the young, fetching food, helping in the maintenance of the nest in the case of certain rodents, and in defending the mother and her young. In other instances all the young of herding animals are looked after by two or more 'nursemaids'. This is the case with giraffes and probably elephants too, and is also known to happen with lions. Many mammals carry their young around with them for a time. Pangolins transport young on the base of the tail, bears and cats use their mouths, and sea otters swim on their backs carrying the young on their abdomen. A curious habit found in some shrews is that of forming caravans, in which one youngster holds onto the mother's tail and the others follow suit, catching hold of the tail of the one in front.

Grebes have the odd habit of carrying their downy young on their backs whilst they are swimming. The young are even carried beneath the surface when the mother dives.

The pink-footed goose has its breeding grounds in the Arctic. Like most other geese it lines its nest with downy feathers.

CHAPTER 20

The wonders of migration

FOR over two thousand years men have been interested, just as we are today, to notice that some birds stay with us all the year round and that others disappear in late summer or early autumn and reappear in the spring. There are other birds that do the reverse of this. They come to us in the autumn and leave us again in the spring. In time various explanations were put forward to account for this. Some of these by our standards were rather stupid, yet they were firmly believed. Cuckoos were supposed to turn into sparrowhawks for the winter and swallows were said to spend the winter at the bottom of lakes. It was not until the middle of the eighteenth century that the second of these was disproved, when a German naturalist, Johann Fritsch, tied pieces of dyed thread on the legs of swallows. Then, when they returned to the same nesting sites the following year, he noted that the threads were still there and the dye had not been washed out.

Ringing or banding a European goldfinch. A Dane, Christian C. Mortensen, began the practice of ringing birds in 1891, using thin pieces of zinc.

During the eighteenth century also naturalists began comparing notes and they began to see that many birds regularly spend the winter in one place and the summer in another. Interest grew and other methods of observation were tried. As more and more lighthouses were built and lightships constructed, it was noticed that birds often flew into the lamps. In the first years of this century William Eagle Clark of the Royal Scottish Museum spent many weeks on lighthouses and lightships taking notes. During the fifty years that followed many others joined in. Bird observatories, like the famous one at Heligoland, were founded. Another famous observatory is at Fair Isle, in the Shetlands.

In 1891, Christian C. Mortensen, in Denmark, began fixing thin pieces of zinc to the feet of birds, the forerunners of the aluminium bird rings used today.

Over ten million birds have since been ringed in Germany, Britain and North America alone. In this, the birds are trapped harmlessly and fitted with light rings on the leg. The ring bears a number and an address and when the bird is caught again the ring tells where it came from and when and where the bird was ringed.

All this information has been patiently plotted until now we have a picture of a vast general post taking

The European swallow is an annual migrant.

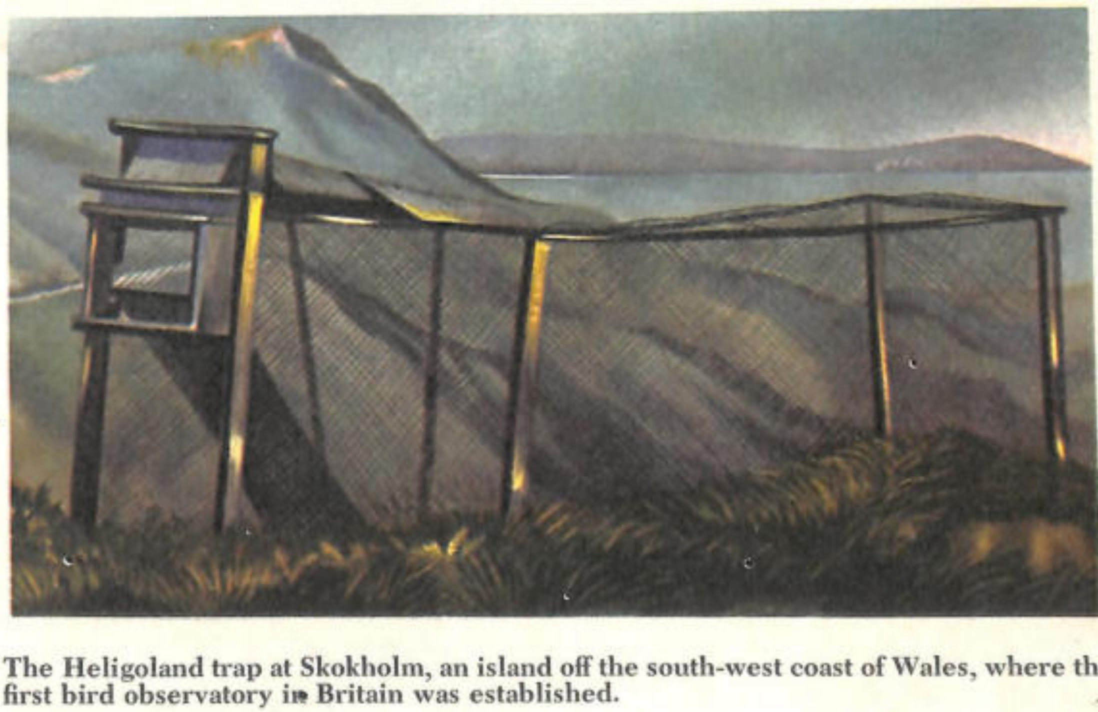
place twice yearly. Some birds fly north and south, others east to west, and back again. Yet others live among the coniferous forests on the slopes of mountains during the summer, flying down to low-lying areas as the weather gets more severe in the winter. Some, like the black-capped chicadee, many starlings, house sparrow and common crow stay in one place all the year round. The British blackbird does little more than move from one garden to another.

Tree swallows gather in huge flocks to migrate in the autumn. From the northern half of the United States and Canada they fly south to Mexico and the regions bordering the Gulf of Mexico. European swallows spend the summer in Europe and the winter in South Africa, some reaching the Cape of Good Hope, a distance of about five thousand miles.

The longest journey is made by the Arctic tern. It nests in the summer in the Arctic and then flies to the Antarctic for the winter (which is the southern summer), a journey each way of eleven thousand miles.

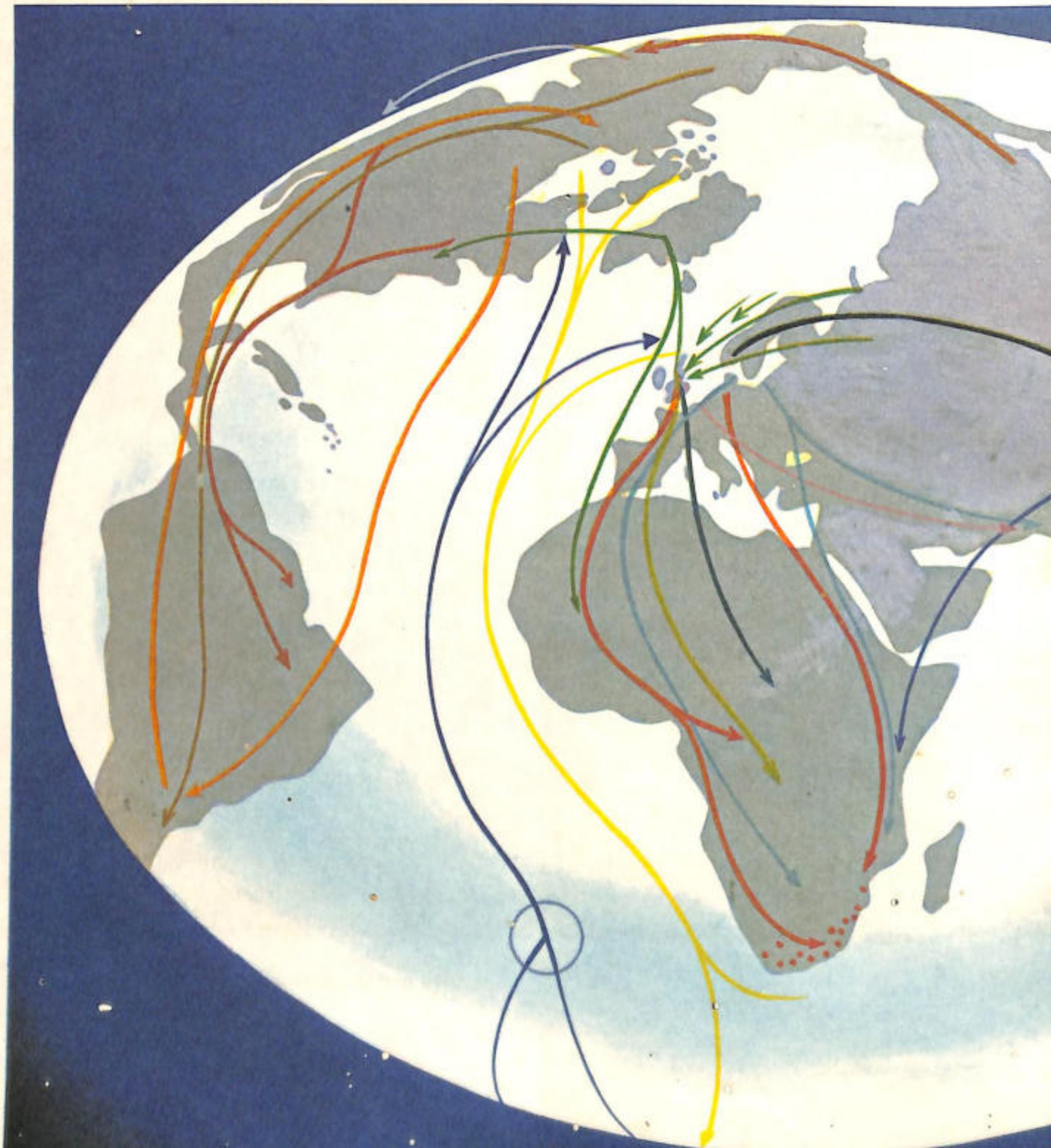
Another of the more remarkable migrations is that of the Golden Plover, which flies from Alaska to the Hawaiian Islands, a journey of two thousand miles without land-fall.

The migration routes are not always in a straight line but tend to follow



The Heligoland trap at Skokholm, an island off the south-west coast of Wales, where the first bird observatory in Britain was established.

well-defined routes along coastlines, through valleys or over mountain ranges. In Europe, migrating birds follow mainly three routes that give the shortest sea crossings: through France and across the Iberian peninsula and the Straits of Gibraltar to Africa, through Italy, or across the Balkans, through Turkey and Asia Minor to Egypt. Often, however, migrations are made over the sea. In America migrations follow mainly four routes. One goes from Alaska southwards along the Pacific coast of North America to Central and South America, a second along the Atlantic coast from parts of Greenland, the Hudson Bay region and Labrador south to the Gulf of Mexico and South America. The third and



fourth routes run almost parallel to each other down the centre of North America. One passes from the Yukon and the western half of North-West Territory southwards above the great plains and the other stretches from the eastern half of North-West Territory and the Hudson Bay area southwards over the Great Lakes, the Mississippi basin and the Gulf of Mexico to Cuba and South America.

On the whole migrating birds do not fly high, only a few hundred feet. It is not unusual to hear flocks of migrating birds flying overhead by night, even in large cities. In the autumn, redwings more especially, coming into Britain from Europe for the winter, can be heard calling as they fly. Sometimes the birds fly very low, especially over the sea and when there is a headwind. Others fly high to avoid the weather. Geese on one occasion were seen migrating at a height of twenty-six thousand feet.

There have been many theories about why birds migrate and how they find their way. One suggestion was that they use the earth's magnetism to guide them, another that they have a kind of racial memory, so that each generation always follows the same route. Another theory was that the older birds act as guides, but then we find that the young cuckoos, who never see their parents, fly south a month after the older cuckoos have gone.

One of the most remarkable features of migrations is the way a bird, such as a swallow, will travel thousands of miles and return to the same nesting site it used the year before. We know that one particular swift made the journey from Britain to Africa every year without fail for four years in succession.

There are obvious advantages and disadvantages in migration. For birds which live in high latitudes the main advantage appears to be the greatly increased range which they obtain. During the summer they are able to inhabit regions which are unsuitable,

◀ **A map showing some of the more important migration routes.**

either through cold or lack of food, in the winter. The fact that they fly north for the summer months does of course mean that they have to fly south with the onset of winter to avoid the unsuitable conditions. But they do inhabit the more northerly latitudes when conditions there are at their best. A bird such as the Arctic tern has the best of both worlds for it enjoys the near continuous light of both the Arctic and the Antarctic summers.

Migration, too, probably ensures that each bird group over the year is spread over, and therefore is exploring, as large an area as possible. This may well increase the chances of their meeting unfavourable conditions, but the reverse also applies. The Greenland wheatear has certainly increased its range northwards in recent times. This has been linked with the higher temperatures which prevail in these latitudes at the present time.

Since 1945 radar has been used extensively to study the migrations. Other new knowledge has also come to light. A German scientist, Dr. G. Kramer, carried out experiments which showed that birds find their way by the sun. Later, it was found that, when birds were kept inside a dome, with the stars painted on the inside of the dome, they changed their position as the ceiling and the stars on it were rotated. Now, it is fairly certain that birds have an 'internal chronometer', that they can take note of the different positions of the sun at different times, and that using a time-sense they can navigate by the sun, or at night by the stars.

This would explain why migrating birds lose themselves in foggy weather. And another reason for this loss of direction could be that they also use landmarks to some extent. A swallow flying to Europe from Africa would set course by the sun and the stars, and these would guide it on its way across Africa and Europe. When it was nearing its destination it would doubtless take note of landmarks to find the particular barn or stable in which it nested last year.

The power of birds to 'home' is indeed remarkable. A bird such as a pigeon can be trained to home from considerable distances. This is done by releasing the pigeon further and further away from its roost. One pigeon found its way home when it was released a thousand miles away. Untrained pigeons, however, do not find their way home as consistently as trained pigeons.

Then we have the surprising story of the scientists in South Georgia, in the Antarctic, who ringed penguins on their nests, and carefully mapped the positions of the nests. Later, the penguins migrated hundreds of miles by swimming or sliding on their bellies over the ice. The next year

A juvenile Manx Shearwater. Manx Shearwaters breed on remote islands off the British coast. In recent experiments several Manx Shearwaters have 'homed' from spectacular distances in even more spectacular times.

they returned to the nesting-area, but the winter had lingered and the whole of South Georgia was covered with snow still, obliterating the landmarks. The penguins began to collect stones from the beach, with which to make their nests as usual, but they deposited these on top of the snow. When the snow melted, the stones began to drop until finally they rested on the ground—in exactly the same places that their nests had been built the year before.

Many other animals besides birds migrate. These include insects (e.g. butterflies), fishes (e.g. salmon, eels), mammals (e.g. whales, seals, antelopes and other herd mammals), and reptiles (e.g. turtles).

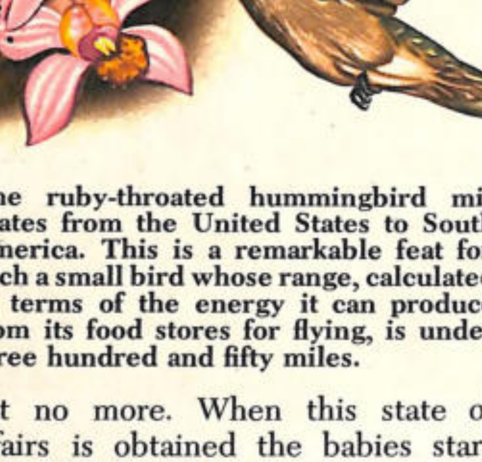
The vast middle-west of the United States is the prairie. Here, just over a hundred years ago, huge herds of buffalo roamed, each herd numbering many thousands. Today the buffalo herds are but meagre vestiges of these once great herds, though even today, thanks to conservation methods, herds several hundred strong can be seen. However, they no longer perform their extensive annual migrations which took them from the south to the north of the prairie during the growth of the new grass there in the spring. Mating took place in the latter part of the summer (as it does today), bitter battles occurring between the bulls. Calves were born during the following April and May, some on the northwards march to fresh pasture, others after the buffaloes had reached their summer grazing grounds. With the onset of the northern winter the buffalo used to trudge southwards leaving the blizzards behind them. In the spring they returned to their northern homes, doing most of their travelling during the daytime and sleeping at night. Today's migrations are strictly local wanderings and are mainly movement from one place to another to find fresh pastures when the ground is covered by snow or to find water when the waterholes dry up in the summer.

In Africa, too, many of the big game animals migrate each year. Wildebeest, zebras and many of the antelopes perform extensive migrations over the game plains of Central and East Africa. The baby antelopes and gazelles are born over a very short period of time as the herds move to new pastures. This is imperative as the mothers and the babies must keep up with the constantly moving herd. Also, because so many babies are born at the same time, the predators gorge themselves until they can

Adélie penguins build a nest of stones which they collect with their beaks.

The ruby-throated hummingbird migrates from the United States to South America. This is a remarkable feat for such a small bird whose range, calculated in terms of the energy it can produce from its food stores for flying, is under three hundred and fifty miles.

eat no more. When this state of affairs is obtained the babies start to survive. If the birth period was spread out probably no babies would survive.



All sorts of animals migrate. Migration may lead to an increase in food and ensures a species is spread over, and is exploring, as large an area as possible. Migration also leads to congregation of animals for breeding purposes.

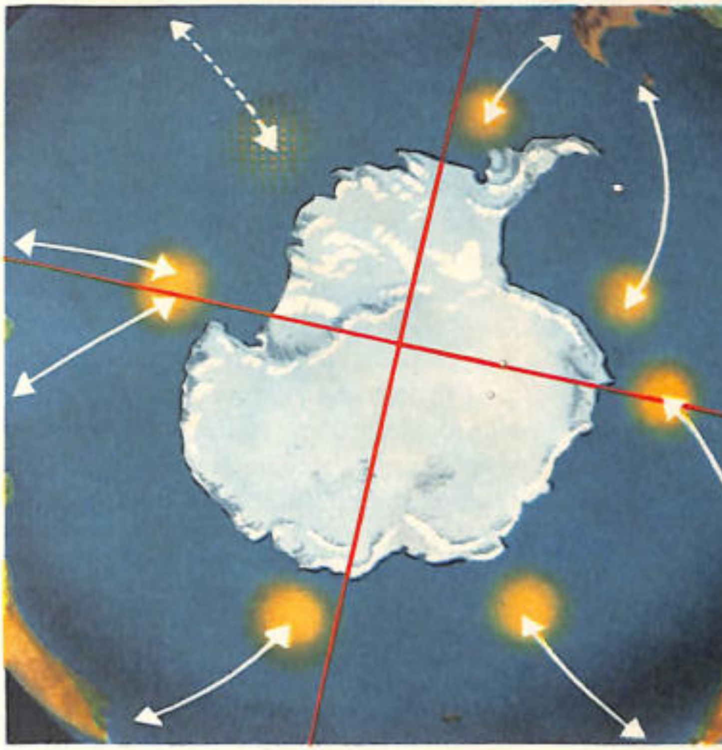
Recent study has brought to light the annual movements of whales and seals. In spring, the male Pacific seals make their way across the seas for a distance of something like two thousand miles, with unerring accuracy. Even during stormy and foggy conditions they find their way through the channels between the Aleutian Islands and arrive finally at the Pribilof Islands. About four weeks later the female seals do the same and here the families settle down and rear their young. In autumn the migration away from the breeding grounds again starts with the males. They swim south to the warmer seas, soon followed by the females and the young seals, and they spend the rest of the year recovering from the strain of breeding and the exertions of their lengthy migrations. Whales show very pronounced migrations. The rorquals spend the summer in the polar seas where they feed on the dense plankton population, particularly the small crustaceans called euphausids. These they strain from the water with the large plates of baleen which line the inside edges of their mouths. In the winter they migrate to warmer temperate and tropical waters. There mating takes place. The female whale carries its young for approximately one year, so that birth takes place the year after mating in the warm tropical waters.

These migrations take place in both Antarctic and Arctic seas. In the Antarctic the whales seem to keep to distinct areas so that there are distinct stocks of whales. For example, whales from the western Weddell Sea area migrate to the seas along the eastern coast of South America; from the Bellinghausen Sea to seas off the coast of Chile; probably a group migrates from the Amundsen Sea up into the Pacific Ocean; from the Ross Sea to the east of New Zealand or between New Zealand and Australia; off Wilkes Land coast to the west of Australia; and off the Enderby Land coast to the east of Africa. A second group from the Weddell Sea area, the east side, migrates to the west of Africa.

From Arctic seas some swim from the Bering Sea to Pacific Islands in winter, others travel from waters off Northern Canada to the West Indies to breed and yet others journey from the Spitzbergen region and winter off the coast of North Africa.

One method of studying whale migration has been to fire white metal discs into the blubber of the whales using a gun. When the whales are caught by the many whale fishery vessels in various regions their movements become known. The whales which leave the Antarctic seas feed very little on their migrations to warmer waters. They must live on the fat which they store during the summer while feeding off the rich supply of plankton. Probably the Arctic whales do the same. The quality of the blubber of whales fished in temperate and tropical waters is very poor when compared with that of the whales caught during the polar summers. Not all whales migrate, for a commercial fishery is run from South Georgia during the winter.

One of the most extraordinary migratory mammals is the Arctic lemming. This little mouse-like animal multiplies rapidly for several years and may become a pest. Then, suddenly, the lemmings seem filled with an urge to gather into flocks and to migrate downhill towards the coast. So persistent is the urge that the little rodents let nothing bar their path. They surge onward through buildings and even swim rivers in order to continue on their way. Almost as suddenly the urge to migrate dies, but not before millions of the lemmings have reached the sea. There they swim as though instinctively across a river and, finding no further bank, become exhausted and drown. No-one knows why this strange suicidal migration takes place.



This map of Antarctica and the surrounding Southern Ocean shows the main whale stocks and their separate migration paths. Not all whales migrate but those that do swim northwards, at the end of the polar summer, for many miles to the seas off the southern parts of South America, Australia, New Zealand and Africa.

Not only are there migratory birds and mammals, but reptiles also show these strange movements. The Galapagos Islands form a group in the Pacific Ocean. Here live the famous turtles, each island having its characteristic type. These animals rear their young on the shores, the mother burying her eggs in the sand. The eggs hatch and when old enough the animals swim out to sea, where they spend their time feeding. In the breeding season, wherever they happen to be, the turtles make for their island birthplace. No-one knows how they find their way through the trackless sea to the beach which reared them.

Amphibia are animals, such as frogs, that spend their adult lives as air-breathing animals but have to return to the water to breed. These animals thus also show migration tendencies. Each spring the frogs emerge from the holes in the ground in which they have been hibernating through the winter and migrate to the ponds and streams. So strong is the urge that no fear of danger impedes the migrant frogs, and thousands die under the wheels of passing traffic as they cross roads. The frogs' return migration is never as spectacular as the spring one, but occasionally people notice a 'plague' of frogs in the summer when the tadpoles emerging from the water as tiny frogs throng the roadsides and paths on their way to their winter headquarters.

Among fish, the habits of the eel and salmon show a remarkable contrast. Salmon spend much of their lives in the sea feeding; but when about one year old, or later in some cases, the salmon, fully fed, feel the urge to seek fresh water. They make their way to the river estuaries and there swim upstream. The urge to swim upriver is irresistible and salmon will even leap waterfalls in order to reach the head-waters of the river. During this time they feed remarkably little, though they will take a fly or two, and for this reason fall victim to fishermen.

But they are not as concerned with feeding as with breeding. In the shallow water of the head of the river the male and female salmon lie side by side in a hollow scraped in the gravel and there the eggs are laid and fertilized. After this the parents drift slowly downstream again towards the sea. They are very weak and many die of disease; but where a salmon is able once again to reach the sea it is often restored to good health by the rich food it finds there. Meanwhile, the

eggs, concealed in the hollow in the river bed, hatch into young salmon, known as alevins. These tiny fish carry a sac of yolk beneath the belly and swim in the water feeding on the yolk and microscopic life. They grow in size until they lose their yolk sac and subsist entirely on what they catch, mainly insects and crustaceans. They are then known as parr. The parr swim downstream and many of them, like the alevins, are eaten by larger fish.

When they reach the sea, they grow as did the parents. If they return in their first year of life they are called grilse.

The mystery of how salmon find the river of their origin after they have been in the sea is still unsolved. In the same way the riddle of the eel's migration has yet to be completely solved.

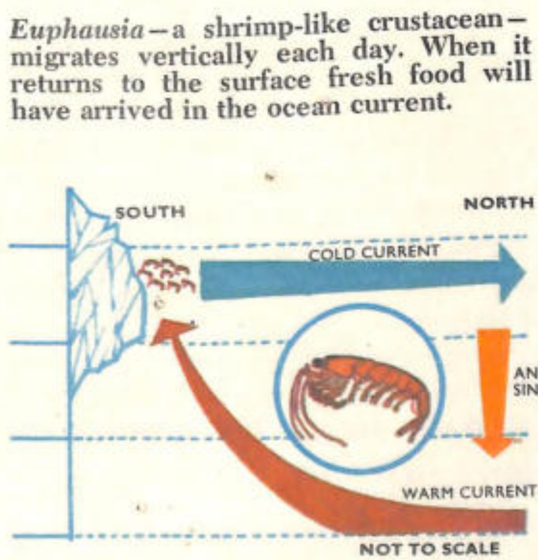
Eels inhabit the rivers and ponds of European countries bordering the North Atlantic. In Europe, the parent eels are seized with the urge to migrate and swim downstream. Eels are able to live out of water for longer than many fish because their gills are kept moist by slime. They can, therefore, cross fields from the ponds in which they live to the rivers. River locks are only a temporary barrier for the eels emerge from the river and regain the water below them. Into the estuaries and out to sea they swim. For many years no-one knew the rest of the story. It is now known that they continue to swim the enormous distance to the Sargasso Sea. There they plunge deep into the ocean and breed many fathoms down. Their bodies are never seen again. Instead, in the Gulf Stream, are found young or developing eels at various stages of growth.

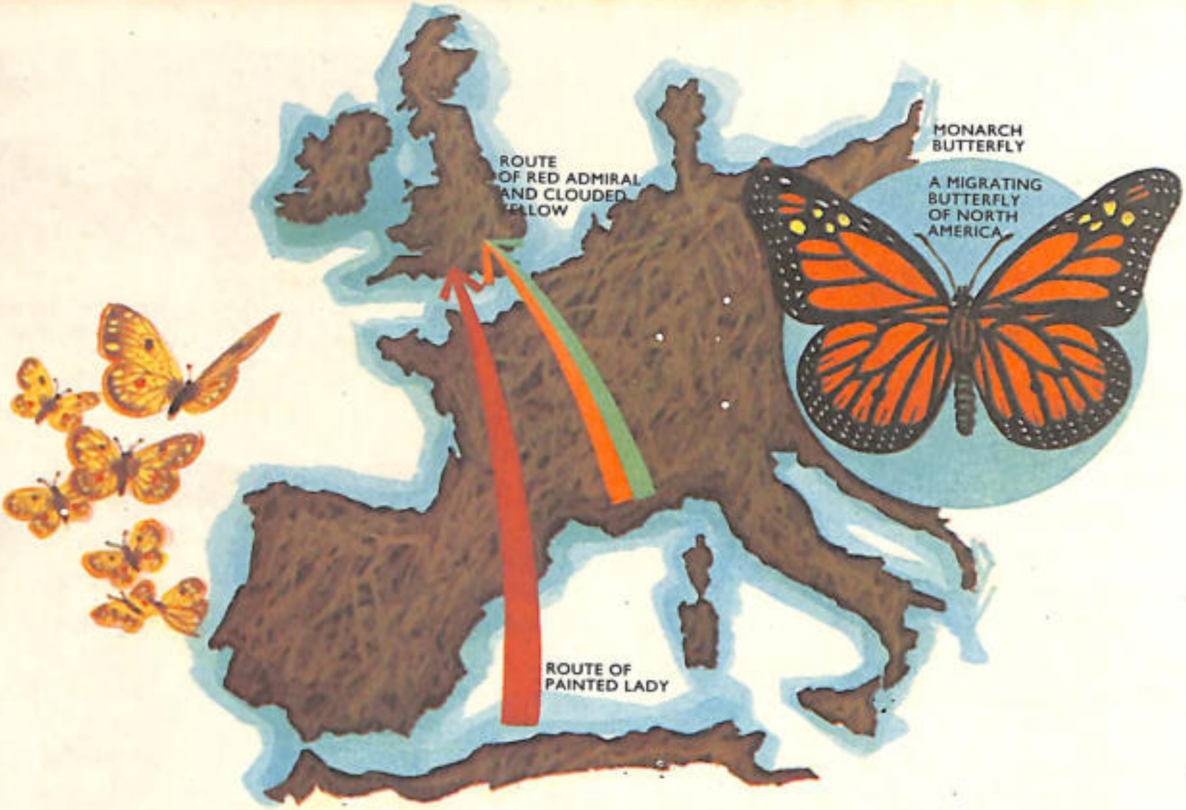
The illustration shows the European eel at various stages of its development.

Near the Bahama Islands, where they are first hatched, these developing eels are flat and leaf-like. This form is maintained as they swim eastwards towards Europe, but they grow as they feed on the life in the surface waters. They do not lose this leaf-like form until they reach the river estuaries when they become long and slender and silvery in colour and are known as elvers. The elvers swim up the estuaries and in the process change in colour and become dark like the parents. They make their way into the upper reaches of the rivers, and even overland into ponds, and there they spend their lives until fully adult and ready to breed again.

Even among insects migration is common. Migratory flights are most commonly seen amongst butterflies. Sometimes clouds of these insects

Euphausia **– a shrimp-like crustacean – migrates vertically each day. When it returns to the surface fresh food will have arrived in the ocean current.**





Several kinds of butterfly migrate to Britain from North Africa. (inset) The monarch butterfly, a well-known migrating butterfly of North America.

can be seen flying steadily in one direction; or swarms of them may be found resting on the ground or on trees. The monarch or milkweed butterfly is a remarkable migrant. Its home is in North America. Here its movements in autumn are well known. In the eastern half of the United States and along the west coast the monarch butterflies fly southwards. Their flights reach Florida, the coasts of Alabama, Mississippi, Louisiana, Texas, southern California and the Mexican border. In spring a return migration takes place though the butterflies do not concentrate in such large numbers. It takes them about two months to reach the north of the United States and Canada.

The cloudless sulphur is another migrant butterfly. It moves from southern parts of the United States to northern states in the summer. The little sulphur migrates occasionally from the coast of North America to the Bermuda Islands, a distance of about six hundred miles.

Insects famous for their long flights, other than butterflies, are locusts. Locusts are a kind of grasshopper which sometimes change their habits from living alone to banding together in vast numbers. Then they take wing and migrate, filling the sky like a huge black cloud, travelling by day and resting by night. During their migration they may travel as much as a thousand miles. Wherever they settle, on crops or on wild plants, they destroy everything edible. The damage which they cause runs into millions of pounds annually and the famines which sometimes result from their destructive activities leave thousands starving.

CHAPTER 21

The life span of animals

WHEN animals grow old, notable changes take place in their appearances. In Man, amongst other things, the skin wrinkles, the hair whitens, and the step becomes uncertain. The direct cause of some of these visible features of age are known. For instance, the hair whitens simply because pigment is no longer produced. But the underlying reasons for the ageing process as a whole are not nearly so certain.

To begin with, the very definition of ageing is difficult. Of the variety of old-age symptoms, several of which can be accurately measured, no one can be taken as a standard of the overall process. For instance, is a slowing of the kidney's filtering action a more 'significant' sign of age than a weakening of muscular activity?

Measurement of any single factor produces variable results and even exceptions to a rule. Unfortunately, long-term measurements of numerous characters for many people or animals have never been systematically kept.

One indirect method of measuring ageing is the susceptibility of the individual to non-infectious diseases. It seems a fundamental truth that most organisms, as they grow older, are less able to adapt themselves to changes and influences in their surroundings. Diseases encroach because animals are no longer able to cope with certain adverse conditions. Excessive coldness and dampness, too little food and similar unfavourable conditions, leave an old animal more vulnerable than younger specimens. Complementary to the falling off in resistance, there is also a decline in the ability to exercise.

Here then is one approach to the process of ageing—discovering just why a body loses its resistance, strength and stamina. A direct answer is that some types of cell, at a certain age, become unable or unlikely to divide. (New cells are produced by the division of an existing cell and its nucleus into two identical parts.) Examples are the muscle cells and nerve cells.

Once the organs made from these cells are complete—the brain for example is composed largely of nerve cells—the cells gradually lose their ability to divide, and do not replace cells in the organ that becomes damaged. Consequently, as losses cannot be made good, the power of the organ declines. A poor memory, for instance, is a common symptom in elderly people and far more time is usually needed for problems to be solved. Other structures known to become impaired in old age are the kidneys, lung tissues, many hormone-producing structures such as the adrenal glands, and taste buds on the tongue. All sorts of disabilities of age can be related to the death and disappearance of cells from the tissues. Associated with this disappearance is the overall decline in body weight. Muscles become emaciated and individual organs lighter.

The actual 'death' of individual cells may possibly be caused in one of two ways. They may become clogged up with insoluble wastes (wastes that will not dissolve—like the fur in a kettle) produced as a consequence of living processes; microscopic examination has shown that muscle and nerve cells accumulate materials in this way. Alternatively changes *(mutations)* in the cell nucleus may cause the cell to lose its ability to function properly. The chemical substances known as DNA, responsible for the construction of genes—the hereditary factors carried on the chromosomes in all nuclei—are probably in some way affected.

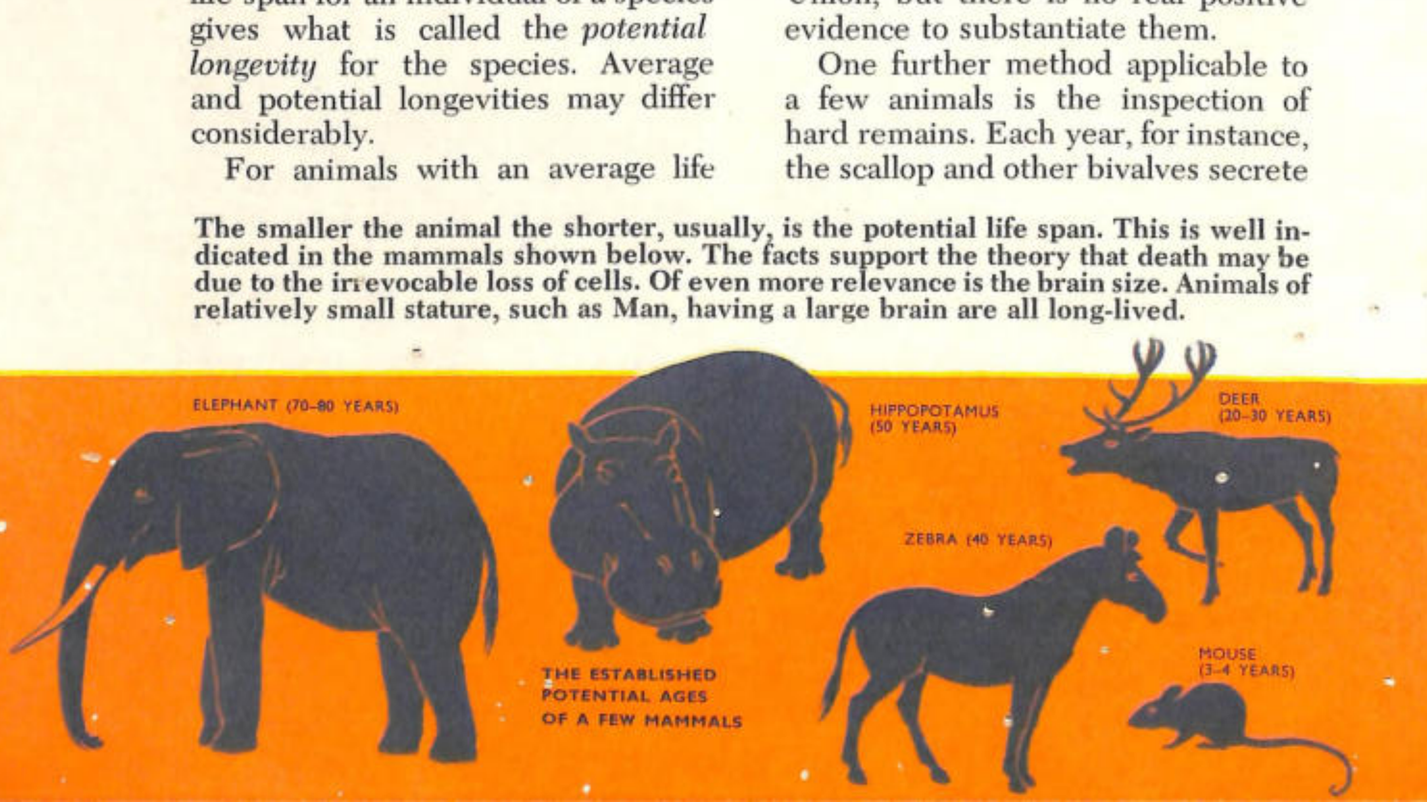
Comparing the known life spans of different animals throws light on ageing. But ways of measuring life spans are rather limited. With relatively short-lived creatures such as fruit flies (life span about two weeks), the animals can be bred in laboratories and, kept free from predators, their natural life spans can be measured by direct observation. Using such a method an average life span can be worked out as well as maximum and minimum life spans. The maximum life span for an individual of a species gives what is called the *potential longevity* for the species. Average and potential longevities may differ considerably.

For animals with an average life span of more than about three years, laboratory methods become impractical. Instead, references must be made to records kept in zoos, kennels and stud farms, however unreliable they may be. Unfortunately agricultural animals are rarely kept for their entire life spans. Of course the results obtained from such records give data only for domesticated animals, or animals kept in captivity. Information for creatures living in the wild is much scantier; but perhaps the increased ringing and tagging of wild animals will help rectify this situation. Unfortunately tales of animals living to a great age have been handed down from generation to generation and it is often very difficult to separate fact from fiction when it comes to determining a creature's age accurately.

In Britain birth records for Man go back to 1837, giving an enormous amount of information concerning human life spans. The maximum age recorded is about 115 years. Claims of far greater life spans than this have come from America and the Soviet Union, but there is no real positive evidence to substantiate them.

One further method applicable to a few animals is the inspection of hard remains. Each year, for instance, the scallop and other bivalves secrete

The smaller the animal the shorter, usually, is the potential life span. This is well indicated in the mammals shown below. The facts support the theory that death may be due to the irrevocable loss of cells. Of even more relevance is the brain size. Animals of relatively small stature, such as Man, having a large brain are all long-lived.



One method of determining age is to look at the hard parts of an animal. The scallop shell has new bands of lime added to the edge each year, producing a series of growth rings.

new bands of calcium carbonate about the edges of their shells. By counting up the various bands the age of the creature can be estimated—rather like finding the age of a tree by counting its growth rings. Other structures which can be similarly used are the scales and certain bones of fishes, the horns of goats and sheep and the wax ear plugs of whales. Approximate evaluations may sometimes be obtained by inspecting the number and the condition of teeth.

If enough information can be gathered, survival charts can be plotted for different species. The

POTENTIAL AGES OF SOME ANIMALS

ANIMAL	APPROXIMATE POTENTIAL AGE IN YEARS	ANIMAL	APPROXIMATE POTENTIAL AGE IN YEARS
EARTHWORM	5-10	RHINOCEROS	45
RABBIT	10-15	LOBSTER	50
SEAL	20	CROCODILE	60
LION	30	MAN	70
NEWT	35	ELEPHANT	70
TOAD	35	SEA ANEMONE	80-100
GORILLA	40	TORTOISE	100-200

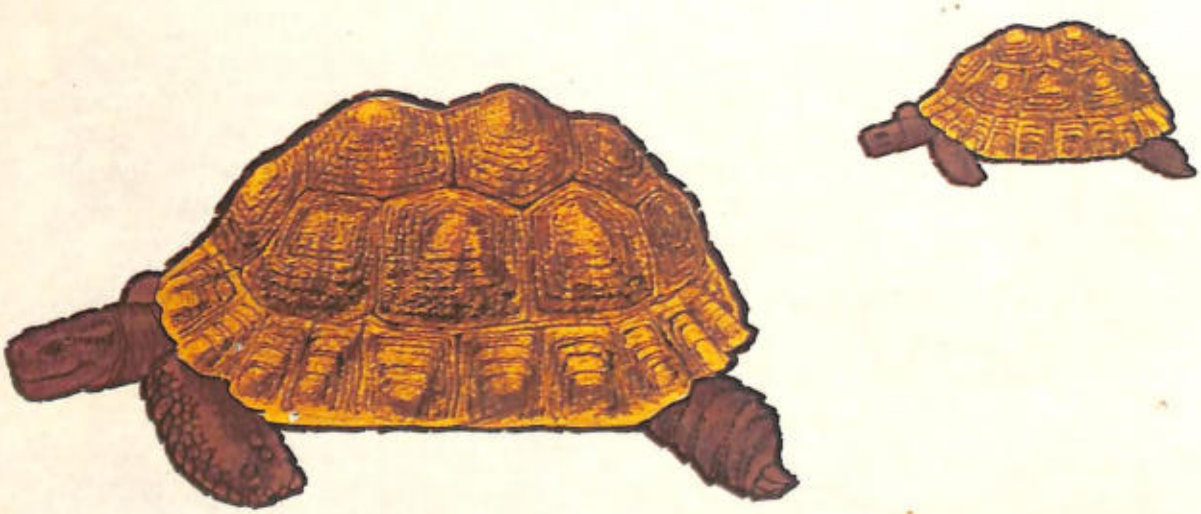
percentage of animals that are still alive after stipulated periods of time are recorded and plotted. For instance, after 10 years more than 90% of horses that survived birth may still be living. After 20 years only about 60% may still be alive.

Inaccuracy and sheer fable has always surrounded the subject of longevity. Men assigned colossal ages to beasts. In the Middle Ages, for instance, a whale was said to live to the age of 1,001. Ages were even given to fanciful creatures such as the unicorn and phoenix.

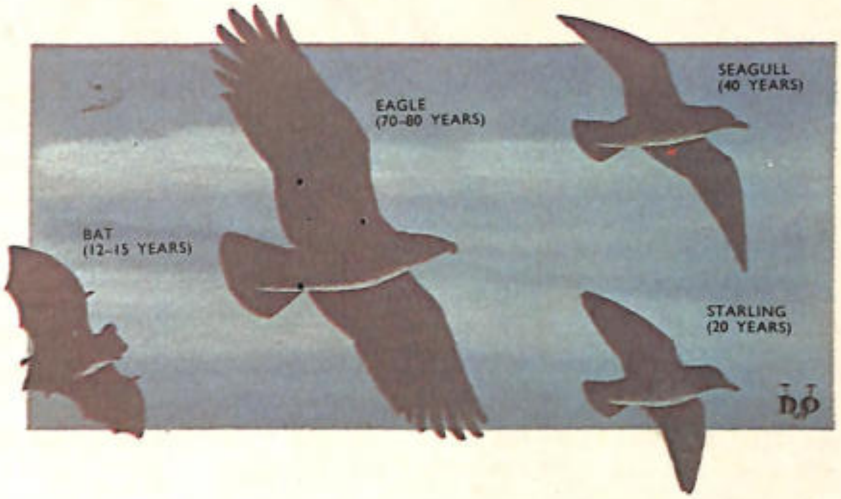
Real objectivity was not introduced into the subject until 1925 when Major Stanley Flower, curator of the Cairo Zoo, published a paper on the recorded lifespans of animals, in zoos throughout the world.

The warm-blooded mammals and birds all age, that is, they decline in vigour and adaptability with time. Amongst the mammals there seems to be some relation between size and lifespan. Larger mammals as a rule live longer. Elephants are known to live to about 70 years, horses up to 40 years, cows 30 years, dogs 20 years or so, mice only about 4 years. These are maximum ages (potential longevities); the average ages are considerably less. Of even greater significance is the relationship between life span and brain size. Large-brained species are all long-lived, despite relatively small statures. Thus Man commonly lives for 70 years or more, out-living the elephant. Such observations are consistent with the theory that ageing is primarily due to cell destruction, particularly nerve cell destruction. The more cells initially present, the longer the life span.

Birds usually have even longer natural life spans than mammals of equal size. Parrots and eagles probably can live for over a hundred years, crows, pigeons, gulls, jays, all 40 years, and even small birds such as



The larger tortoises live well over a hundred years and some may approach two hundred years. Perhaps the slowness to age is due in some way to a continuous if imperceptible increase in size throughout their lives.



Size for size, birds outlive mammals. This, despite their very high temperature and the speed at which their bodies work. Of mammals, bats have unexpectedly long lives; perhaps a low rate of body activity at rest and during hibernation is significant in this instance.

the chaffinch, when kept from natural competition, reach twenty years or so (though under natural competition their average life span is very much shorter).

Coming to cold-blooded amphibians and reptiles, natural life spans begin to lengthen. Perhaps the lower metabolic rate of cold-blooded creatures is an important factor. Though against this, birds, animals with the highest metabolic rate of all, tend to outlive mammals of equal size.

Small frogs, toads and newts all can live for more than twenty years. Tortoises commonly live to be a century and large specimens may exceed 150 years, even approach 200 years. Some fishes, too, are known to reach colossal ages. Carp reaches 50 years and sturgeon perhaps 100 years.

One possible reason for the longevity of some of the larger cold-blooded creatures is that they continually grow. Perhaps, unlike the birds and mammals, they do not have a fixed adult size. Increasing almost indefinitely in size (though the rate of growth becomes slower and slower) a creature such as the tortoise may age almost imperceptibly.

The natural life spans of invertebrate animals are far more variable, from a few days (mayflies), to 60 years or more (mussels). A queen-bee lives for about eight years, a worker bee for one. Some of the very simple unicellular animals, in fact, do not appear to age at all. They grow to a certain size and then divide into two. This does not, of course, mean that they live for ever. But those that do die are killed or destroyed by mechanisms which would be lethal at any age.

The great differences in longevity between species and even individuals of the same species rather indicate that whether or not there is primary cause for ageing, many other genetical and environmental factors have influence. Such factors can only be assessed after exhaustive research into the ageing of all sorts of species of animal.

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