CHAPTER NINETEEN

THE WORKING OF ECOSYSTEMS

The study of organisms in relation to their environment is known as **ecology.** This science developed in response to the increasing awareness of inter-relationships between plants, animals and their physical habitats. The great voyages of exploration in the late eighteenth and early ninteenth centuries accumulated vast amounts of information about the diversity and distribution of species throughout the world and led naturalists to enquire into the causes of the patterns they found. Early workers acknowledged the importance of the climate in which organisms lived, and attempted climatic classifications of vegetation. One of the earliest of these was by the German biologist Köppen who, in 1918, tried to establish boundaries for vegetational and climatic zones (Chapter Sixteen). At about the same time botanists were studying plant communities and realising the importance of animals in these; their classifications of vegetation included the **index animals** typically associated with certain community types. Similarly zoologists were emphasising the interdependence between animals and plants. Early this century naturalists were dividing plants and animals of the world into **biotic associations** or **biomes.** These were large areas in which recognisable associations of species occurred.

Attempts were made to replace this distributional approach with a more functional concept to include plants, animals and their physical habitat working together as a system. A system of organisms functioning together with their non-living environment became known as an **ecosystem.** In this chapter we shall examine the structure and function of ecosystems.

The Structure of Ecosystems

The concept of the ecosystem is very broad and flexible. It can be applied to any situation where organisms function together with their non-living environment in such a way that there is interchange of materials between them even if the system only lasts for a short time. We can look on puddles, fields, forests and the whole world as ecosystems. Ecosystems are **open systems**, and therefore have flows of energy and materials across their boundaries. Sometimes it is easy to recognise units to study as ecosystems, such as a pond or a wood, but often the boundaries of the system are more arbitrarily placed round the area to be examined, such as a patch of grassland or part of a desert. But whatever the size of the area to be studied the ecosystem concept is a useful model for examining the structure and function of life.

There are four basic components of an ecosystem. First, the **abiotic** part, which is the non-living environment. Second, the **producers** or **autotrophs**, the green plants capable of producing their own food by using the energy of sunlight to make carbohydrates from water and carbon dioxide; this process is called **photosynthesis**. Third, there are the **consumers** or **heterotrophs**. These are animals which obtain their food by eating plants or other animals. The heterotrophs in any ecosystem can be divided into groups by their feeding habits:

herbivores eat only living plant material; **detritivores** feed on dead plant and animal material; **carnivores** eat other animals; and **omnivores**, as the name suggests, eat both plant and animal material. Fourth, there are the **decomposers**, such as the bacteria and fungi that promote decay.

An Example of a Simple Aquatic Ecosystem

The four basic components mentioned above can be recognised in very different types of ecosystem and it would be useful at this point to look at one example. Small ponds are a useful starting-point for ecosystem studies because they demonstrate the interrelationships between the abiotic (non-living) and the biotic (living) parts of the system very clearly (Fig. 19.1).

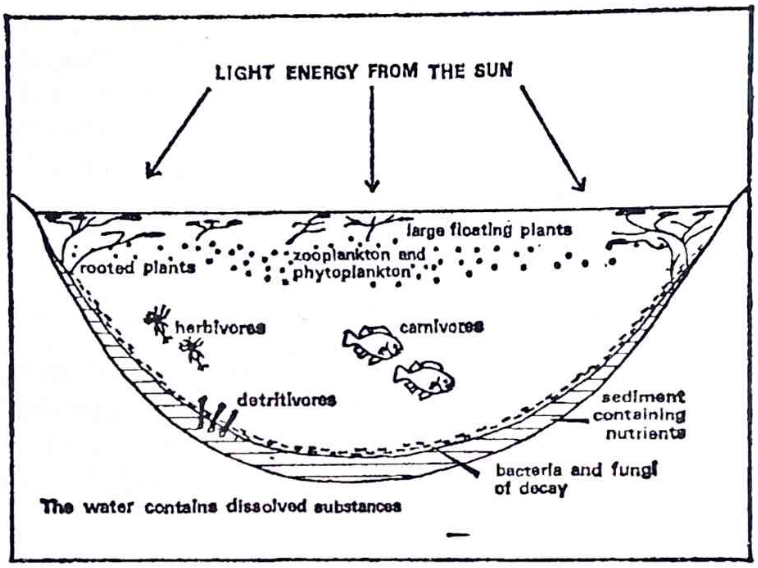

Fig. 19.1. The pond as a simple ecosystem.

Inorganic and organic substances such as water, oxygen, carbon dioxide, calcium and mineral salts form the abiotic part of the system. A small percentage of these will be dissolved in the pond water but most will be present as solids in the sediment at the bottom of the pond. The sediments act as a reserve of nutrients for the plants and animals.

The autotrophs in the pond can be of two main types. They can either be large plants which are rooted or floating, or they can be minute plants, usually algae, called **phytoplankton**. The phytoplankton give the water a green tinge and are distributed throughout the depth of the pond providing there is sufficient light for photosynthesis. They are often very important for producing food in the system and in deep ponds or lakes they usually produce a greater total amount of food than the large plants.

In the heterotroph group of organisms, the herbivores, feeding directly on living plant material, will be of two types, namely the minute **zooplankton**, which feed on the phytoplankton, and the larger animals such as herbivorous fish. The carnivores will include a range of organisms from predaceous insects to game fish which feed on herbivorous fish or each other. There may also be detritivores living at the bottom of the pond, feeding on the dead plant material falling through the water from the autotrophs.

The last main component of the system, the decomposers, will include aquatic bacteria and fungi, and will be distributed throughout the pond. They will be especially prolific at the interface between the water and the sediments where dead plant and animals accumulate. The bodies of these dead organisms will usually decay rapidly due to the continued action of the detritivores and the decomposers.

The Trophic Structure of Ecosystems

The organisation and pattern of feeding in an ecosystem is known as the **trophic structure**. In the example of the pond ecosystem, we have seen that there is a definite arrangement of the main components to form a sequence of levels of eating. This sequence of consumer levels is known as a **food chain**. There are two basic sorts of food chain: a grazing food chain in which the plants are eaten live by herbivores, and a detrital food chain in which the plants are eaten as dead material by detritivores. The two sorts of chain vary in importance in different ecosystems; for example, in a forest ecosystem the detrital chain is often more important, but in a marine ecosystem the grazing chain is usually more important.

Food chains can be simple linear chains which take the form of

plants → herbivores → carnivores → decomposers
(e.g. grass → vole → weasel → bacteria)

but usually the situation is more complicated. Often there are more than four steps in the chain. For example, carnivores could feed on other carnivores so that food chains would take the form of

plants → herbivores → carnivores (1) → carnivores (2)
— → carnivores (3) → decomposers

In addition, some animals consume a wide variety of food; herbivores may eat several sorts of plants, and carnivores may eat several different herbivores and other carnivores. This means that linear food chains will interconnect to form **food webs**. Grazing and detrital food chains often link in this way at the carnivore level. The patterns of food levels in ecosystems can be determined by techniques such as the analysis of the gut contents of animals to see what they have eaten, or by introducing radioactive tracers into plants and monitoring their progress through the heterotrophs.

Fig. 19.2 illustrates the food web associated with the adult herring. This shows that there are many links between the food chains in which the adult herring acts as a carnivore.

Organisms feeding at the same number of steps on a food chain from the autotrophs are said to be at the same **trophic level**. The green plants are at the first trophic level, herbivores the second, carnivores feeding on herbivores the third, and so on. This trophic classification is one of *function*, not of populations, so that an omnivorous species could occupy more than one trophic level.

Energy Flow and the Standing Crop

The energy of sunlight fixed in food production by green plants is passed through the ecosystem by food chains and webs from one trophic level to the

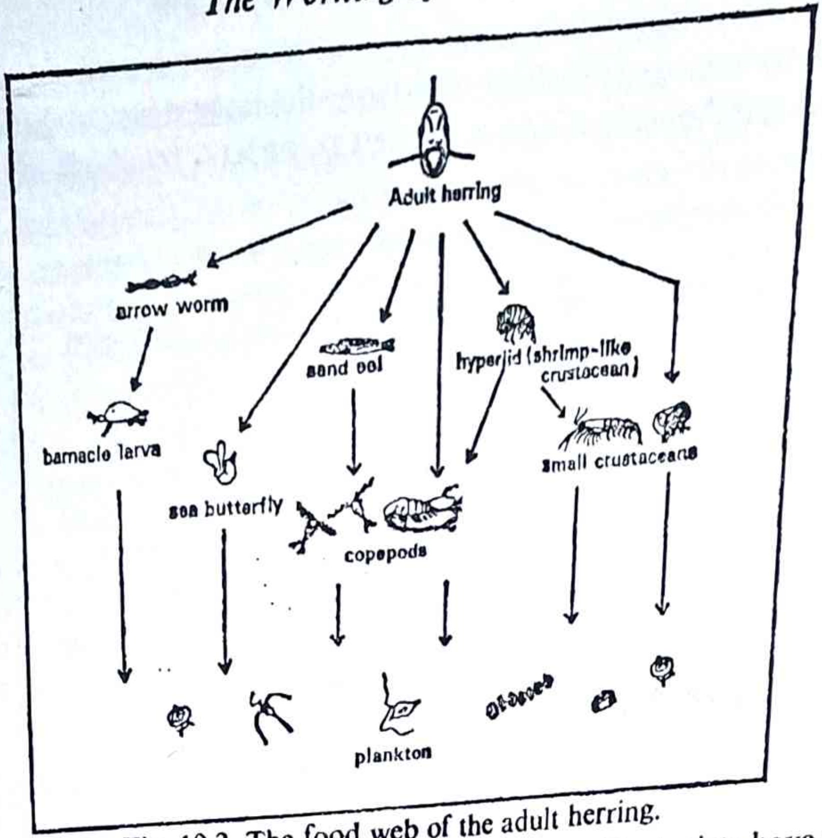

Fig. 19.2. The food web of the adult herring.

next. In this way energy *flows* through the ecosystem. Ecologists have traditionally looked at energy flow in ecosystems in the same way as other scientists have examined energy flow in physical systems. They have applied the first and second laws of thermodynamics. The first of these laws states that energy cannot be created or destroyed. It can only be transformed from one sort to another—for example, light energy into food energy as in photosynthesis. This means that all the energy fixed as food by the green plants must either be passed through the system, be stored in it, or escape from it.

We have already looked at the way in which energy is passed through the system in food chains and webs. Storage of energy in the system is shown by the amount of living material in both the plants and animals present. The amount of living material present is called the **standing crop**. This can be expressed in several ways but is usually shown as **biomass** (living material) per unit area, measured as dry weight, ash weight or calorific value. Ecologists usually look at the standing crop at each trophic level as this is an indication of the pattern of energy flow through the system.

Usually the amount of standing crop in each trophic level decreases with each step on the food chain away from the plants. This can be shown diagrammatically by **trophic pyramids** as in Fig. 19.3. Each bar represents a trophic level and the size of the bar is proportional to the amount of biomass at that level. The characteristic pattern is due to two main reasons. First, the second law of thermodynamics states that no transformation of energy is 100 per cent efficient—there is always some loss of energy as heat. This means that when herbivores eat plants to get food for growth and maintenance of their bodies, they will not be able to use all the food energy in the plant material. In converting plant substances into animal substances there will be loss of energy as heat, which will escape from the system. Therefore there will be large losses of energy *between* trophic levels. Second, there will be energy losses *within* each trophic level. All organisms must respire to live; **respiration** involves the oxidation of carbohydrates to release energy. Therefore energy will be lost from the trophic level by the respiration of the organisms in it.

The flow of energy will thus decrease with each successive trophic level. There will be less energy available for use at the later steps on the food chains and so less standing crop will be supported at the later trophic levels.

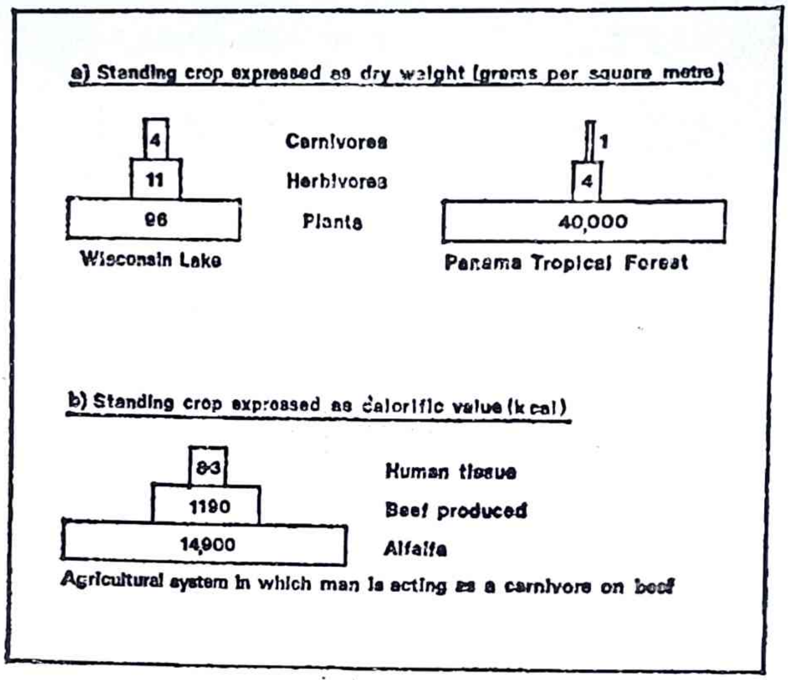

Fig. 19.3. Examples of trophic pyramids.

Productivity

In ecosystems the rate of production of organic matter is known as productivity. **Primary** productivity refers to production at the autotroph level, and **secondary** productivity refers to production at the heterotroph level.

We can divide productivity still further into **gross** and **net**. Gross productivity is the total amount of organic matter produced, and net productivity is the amount of organic matter left after some has been used in respiration. Primary gross productivity will depend on the efficiency of photosynthesis and the amount of light energy coming into the system. The intensity and duration of sunlight varies globally (Chapter Ten) so that the potential for gross primary productivity will vary greatly with different ecosystems. Vegetation at the equator will receive far more light energy in a year than vegetation at high latitudes. The efficiency of photosynthesis itself depends on many factors such as temperature, the availability of nutrients and the age and species of individuals. Net primary productivity will be determined by the relative rates of respiration (using up carbohydrates) and photosynthesis (producing carbohydrates). In reasonable conditions photosynthesis proceeds up to thirty times faster than respiration but it must be remembered that it only occurs in the light.

Very few detailed quantitative studies of primary productivity have been conducted, but those that have all reveal very low rates. Of the light energy impinging on the surface of vegetation as little as one to five per cent may be trapped as food energy. Yet despite these low figures enough energy is trapped to maintain all life. It is interesting that where comparisons have been made, most agricultural systems have been found to be far less productive than natural systems in the same environments.

Secondary productivity will depend on the conversion of plant substances to animal substances. The efficiency of transfer of energy from one trophic level to the next is known as **ecological efficiency**. The efficiency of transfer from autotrophs to heterotrophs is low. Most studies now estimate it to be about ten per cent in natural ecosystems. The majority of animals have their greatest rates of net productivity when they are young as this is the time when they are most vulnerable. It is an ecological advantage to grow quickly in order to compete with other animals for survival. Even at their most productive, animals rarely exceed a 35 per cent efficiency of energy transfer.

At first it may seem strange that productivity in ecosystems should be so low, but it must be remembered that there are many pressures in the environment to influence the evolution of species. Selective forces for breeding, escaping from predators or maintaining territory may take precedence over the importance of ecological efficiency.

Modelling Energy Flows and Productivity

For convenience many ecologists have modelled energy flowpaths by grouping organisms by their trophic levels and indicating the energy flow as relationships between these levels. The levels can be shown diagrammatically as boxes for plants, herbivores, etc., connected by arrows or bars representing energy flow. The bars can be of varying width, proportional to the amount of energy flowing. In reality this is extremely difficult to do as species often have many different roles in the system and cannot be neatly placed in trophic levels. Very few so called 'carnivores' are species that feed only as true carnivores. In nature, energy flows through the ecosystem by a complex of encounters between species, leading to interaction between trophic levels. Energy flow paths are rarely simple. Frequently there are feedback loops; one species may feed on the faeces of another so that energy in the faecal material does not go to the decomposers but is taken back into the system at a lower trophic level.

Many ecologists have modelled energy flow and productivity by using a **hydraulic analogy**. Energy is shown as flowing in pipes of various widths between trophic levels. Loss of energy in conversion or by respiration is shown as bouncing off the trophic level (Fig. 19.4). Although this model gives a neat visual impression of the functioning of an ecosystem it should be remembered that it is an extreme abstraction of reality and as such its use is limited.

Ecological Niche and Species Structure

The role that an organism takes in the ecosystem is known as its **ecological niche**. Species vary in the breadth of the roles performed. Some animals are **specialists** in their feeding habits—such as the koala bear, which eats only eucalyptus leaves—and others are **generalists**, consuming a wide variety of food. Some extreme generalists such as *Euglena*, a unicellular alga, can function either as autotrophs or heterotrophs. Usually the specialists in the system are more efficient at using their resources and therefore became abundant when their particular food supply is ample. Despite this advantage, they are vulnerable if conditions change so that their food becomes rare, as they will not be able to switch to an alternative. The majority of animals occupy a broad ecological niche and so are generalists in their feeding habits. Most exhibit a