

# Energy transfer

*You may have wondered why the real-life food chains you have studied aren't very long. In this article we show how the loss of energy from food chains limits the number of animals that can survive on the energy fixed by a patch of vegetation.*

The Earth's outer atmosphere is irradiated by huge amounts of energy from the Sun. The atmosphere reflects and absorbs some of this energy, but most reaches the Earth's surface. Energy enters food chains only when sunlight is used in photosynthesis.

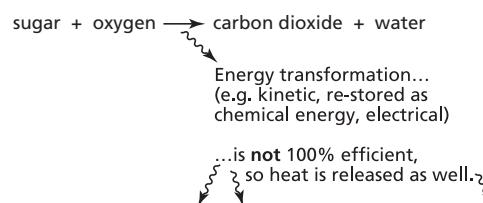
Over 3 million kilojoules of visible light energy reaches each square metre of ground in the UK in a year. Relatively little of this kick-starts food chains through the process of photosynthesis. Some is reflected by bare soil and some is absorbed, heating the soil — think of walking barefoot on a dry sandy beach on a sunny day. Plants can benefit from the warming of soil because it makes them grow faster. About half of the light energy is used evaporating water from moist soil; this is what dries the ground out after rain.

Plant leaves reflect and transmit green and yellow light — which is why they look green — so this energy is lost too. They absorb red and blue wavelengths of light and use them for photosynthesis.

Of each thousand kilojoules reaching the Earth's surface less than 25 kJ/m<sup>2</sup> is used for photosynthesis. This small amount is what ecosystems are built on.

## PLANTS AS FIXERS

Only a portion of the sugar made in photosynthesis contributes to the increase in biomass. Some of it is used in *respiration* as a source of energy to drive the synthesis of other substances the plant needs in its growth. The energy transformations involved are not 100% efficient so energy is also lost to the environment as *heat* (Figure 1). Only the molecules used in tissues, for example sugars used to make cellulose for new cell walls, proteins for cytoplasm and lipids for waterproofing the leaves, contribute to the biomass of plants. This biomass amounts to 1–5% of the light energy received per square metre and is the source of energy for primary consumers.



## GCSE key words

Efficiency of energy transfer  
Heat  
Respiration  
Egestion  
Trophic level

Steve Hopkin/Ardea

**Above:** Food webs are very complex. It is not only large herbivores that eat plants.

- Why do plants grow faster in warmer ground?  
*Hint: think about rates of chemical reactions.*

**Figure 1** Energy is mostly lost as a result of respiration.

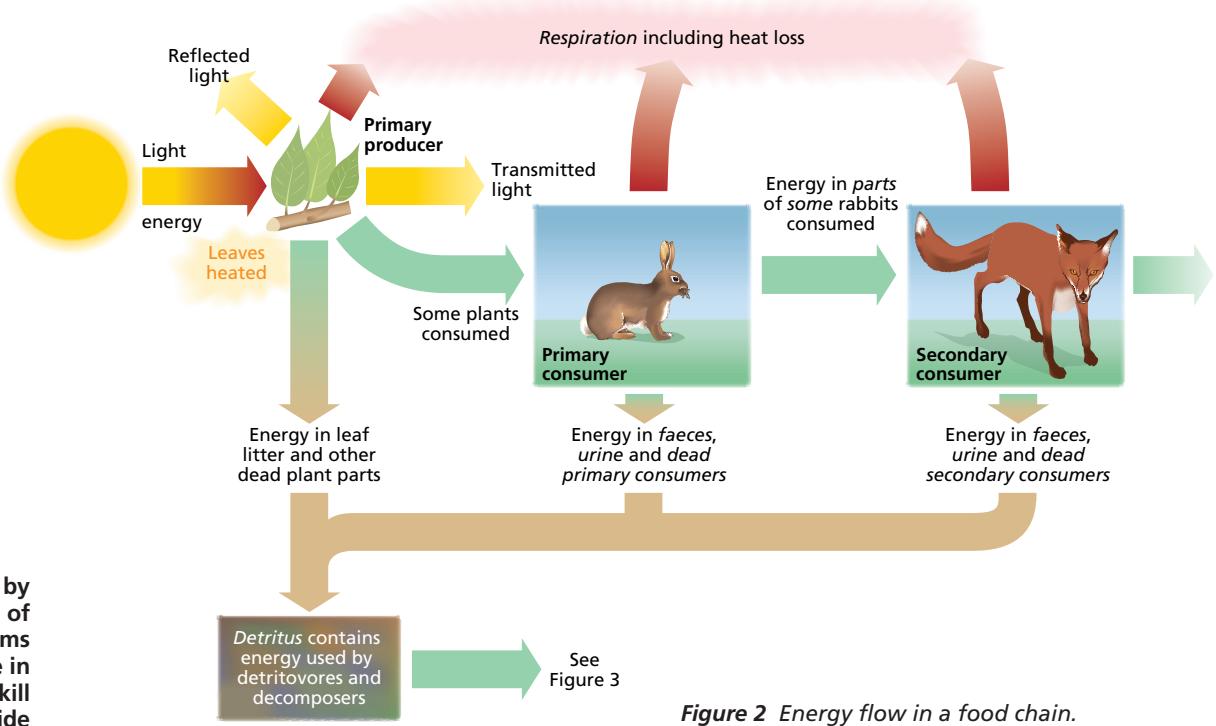


Figure 2 Energy flow in a food chain.

## CONSUMING EXPERIENCES

A herbivore — a primary consumer — browses on vegetation. Of course the energy in the parts of the plant it does not eat is lost to that food chain, but it may enter another. The roots or remnants of leaves damaged by large herbivores may be eaten by other small herbivores such as slugs or millipedes.

Food webs are very complex. Ecologists often consider energy transfer between trophic levels rather than energy passing down a food chain. They measure the energy per square metre fixed by primary producers, how much energy passes to the

primary consumers grazing on that area of vegetation, how much then passes on to secondary consumers, and so on. It is very difficult to accurately measure and portray energy transfer because animals' feeding habits can be complex (see Box 2).

Quite a lot of the energy in the biomass an animal consumes is not available for growth. For example, cellulose, the polymer of glucose making up plant cell walls, is by far the commonest substance in vegetation, but few herbivores can digest it and use its energy. Even animals that have microbes in their gut to digest cellulose, such as cows, cannot make use of all of it. Most cellulose is egested as faeces. However

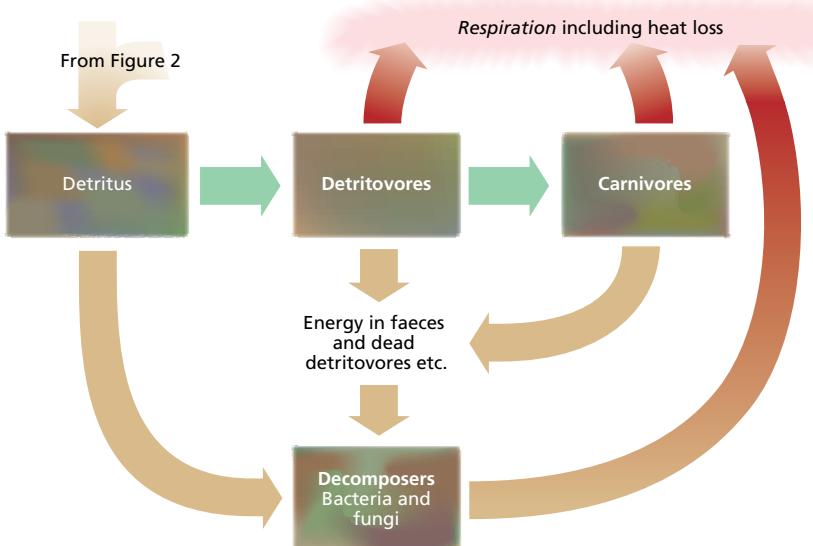


Figure 3 What happens to the energy in detritus.

## BOX 1 DIFFICULTIES MEASURING ENERGY TRANSFER

It is difficult to measure how much of the energy present in 1 m<sup>2</sup> of grassland passes into each trophic level above it. We can quantify the energy transfer in only the simplest systems with a few organisms and few levels. Such simple systems are rare, and so there are few fully-investigated examples.

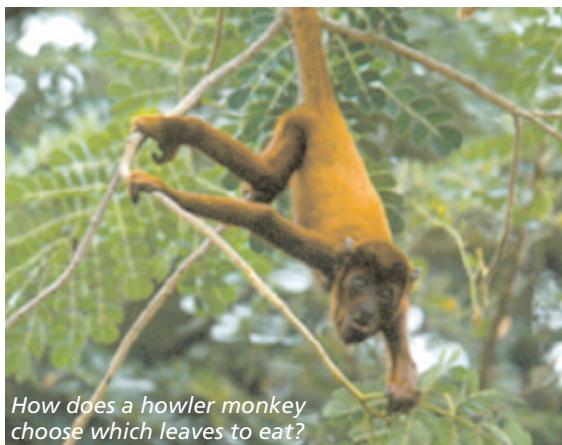
Food chains are simplified versions of the real-life situation in which predators such as starlings eat several prey organisms and so link several food chains — which change as they migrate across Europe each year. Field mice fall victim to many different predators, herbivores browse on different food plants in different places. It does not get easier if scientists attempt to quantify energy transfer in a food web, as many predators and scavengers such as foxes feed on primary and secondary consumers as well as taking the occasional fruit meal.

## BOX 2 FORAGING STRATEGY

Animals make life complicated for ecologists trying to estimate who eats how much. Errors creep in because animals do not forage evenly within a habitat, they are choosy about what and where they eat. They have to make important decisions when foraging, and choosing the wrong strategy may impair their chances of survival.

Howler monkeys eat leaves but may completely ignore those of nearby trees and search for the rare trees whose leaves contain less of a toxic chemical. They eat just the youngest leaves with the least toxin and fibre. They will select individual mature leaves but only if they have a high protein content. A 'snapshot' visit by an ecologist estimating leaves consumed may not accurately reflect the situation.

Animals forage away from their usual territory from time to time if it makes sense in terms of energy lost and gained. A starling will ignore small soil invertebrates where it usually feeds and use slightly more energy to travel further for larger energy-rich leatherjackets. Again this upsets the energy figures.



How does a howler monkey choose which leaves to eat?

How many elephants can a game park support?



Ferrero/Labat/Ardea

## BOX 3 CARRYING CAPACITY

The productivity of an area of vegetation (that is energy fixed per square metre per year) limits how many animals can live there. The total energy fixed each year in plant biomass in an area can feed many different herbivores, but there is a limit to the total animal mass it can support. If there are too many herbivores the vegetation will be grazed faster than it grows and will not be able to flower, set seed and replace itself.

The number, or biomass, of herbivores that can be maintained in an area is called its **carrying capacity**. There are also limits to the number of predators that can live on the herbivores.

This information is important to people managing areas of land. Farmers need to know, for example, how many sheep can be satisfactorily grazed on a given size of farm. Similarly, game park managers have to know how many elephants can graze in the park. A growing population risks damaging the vegetation so badly that the whole system becomes unbalanced.

It has been estimated that a human needs eight times as much energy as a crocodile of the same size. This is because humans need to maintain a constant body temperature, normally above that of their surroundings.

microbes in the soil — fungi and bacteria — can degrade cellulose in dead plant material and herbivore faeces to release organic compounds. They can absorb and use these for their own respiration and growth. In addition, animals do not use all the nutrients absorbed from the gut, and some energy is lost as urea in *urine*.

## RESPIRATION LOSSES

Animals use sugars in respiration to provide energy for movement and metabolism; again, the energy transformations are not 100% efficient so energy is lost to the environment as heat (Figure 1). Mammals and birds use most of their energy intake to maintain a steady body temperature.

Less than 10% of the energy taken in ends up in new biomass. This biomass is the source of energy for organisms at the *next* trophic level in the chain.

As Figures 2 and 3 show, the diminishing proportion of the energy originally stored in plants that is transferred on through the chain severely reduces the quantity of energy available for the animals in the next level.

As the animals at the next level use energy in similar ways, there is a similar reduction in the energy fixed as biomass. Predators take the most easily accessible energy-rich parts of their prey, such as the liver, and leave less digestible parts such as fur, bone and feathers. However these are a food source for scavengers or detritovores (Figure 3).

By the time energy has been passed from plants to secondary consumers there is very little left for top carnivores. A family of carnivores needs a huge territory of vegetation to support it (see Box 3).

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● Try to work out the size of territory a domestic cat would need if it had to fend for itself.