Bio Factsheet

Number 16

Flow of Energy through Ecosystems

The sun is the ultimate source of energy on earth. The process of nuclear fusion in the sun releases a huge amount of energy which reaches the earth in the form of electromagnetic radiation. It is one small part of this electromagnetic radiation - visible light - which is trapped by photosynthetic organisms. Such organisms then convert this light energy into organic substances which effectively makes solar energy available to the animal kingdom.

On A-Level syllabuses, there are two frequently-examined key principles:

1. The overriding importance of green plants in making energy available in the first place.

2. That only a small amount of the total energy received from the sun is captured by plants and that the amount of energy available at each trophic level decreases.

Only a small fraction of the total energy which reaches the earth is captured by green plants. This is because most of the energy is reflected or absorbed by the atmosphere. Much of the energy which does penetrate the atmosphere does not hit plants. Some of the energy which **is** intercepted by plants passes straight through leaves without hitting chloroplasts or is reflected from plants or is of a wavelength which does not excite pigment molecules (see Factsheet 2: Photosynthesis). As a result of these losses, less than 1% of the total available energy is captured in photosynthesis.

The small amount of solar energy which is captured by green plants is absorbed by the green pigment chlorophyll. During the process of photosynthesis, this solar energy is transformed into chemical energy in the form of sugars using carbon dioxide and water. This chemical energy is then available to animals, bacteria and fungi.

The light energy which is captured by chlorophyll molecules is used to generate ATP. However, the plant uses most of this ATP in maintaining its own metabolism and since all metabolic reactions are inefficient, much energy is lost as heat. **Gross primary production (GPP)** is the total amount of energy or organic matter captured or fixed by green plants, but respiratory losses (in the form of heat) mean that only **net primary production (NPP)** is available as the source of energy for animals which consume the plants (herbivores). In other words, **NPP = GPP - R**. In consuming plants, herbivores are in effect receiving light energy in the form of organic molecules - carbohydrates, fats, proteins etc. and without the process of photosynthesis, the vast majority of the animal kingdom would be unable to gain any energy at all.

Green plants therefore represent trophic level 1 and are known as **primary producers**. These are then eaten by **primary consumers** which use the complex organic molecules which make up the body of the plant as their energy source. Organisms which feed on primary consumers are termed **secondary consumers** and those that feed on secondary consumers are termed **tertiary consumers**. This is shown diagrammatically in a food chain (Fig 1).

Fig 1. Food Chain

Spruce tree →	**Bark Beetle →**	**Chaffinch→**	**Sparrowhawk**
Primary Producer	Primary Consumer	Secondary Consumer	Tertiary Consumer

However, organisms do not usually feed on just one type of organism, so food webs - interconnected food chains - are more realistic.

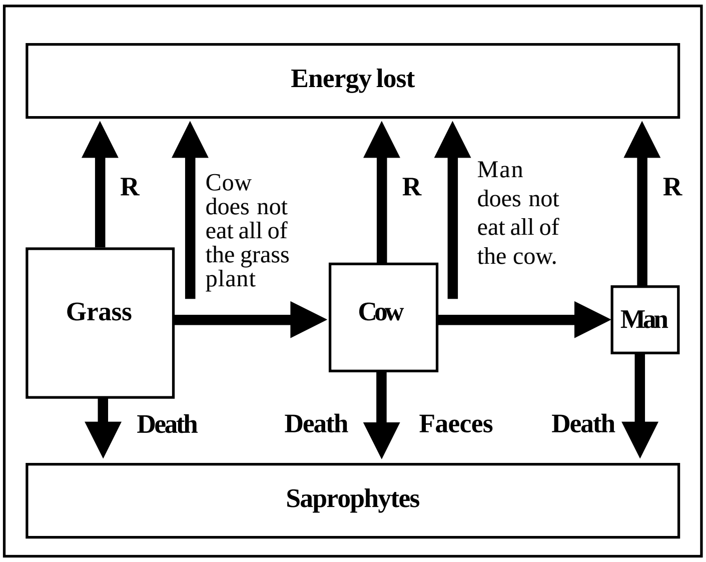
Only about 1-10% of the total energy contained in plants is obtained by primary consumers. This is because:

1. Plants use most of the ATP they produce maintaining their own metabolism.

2. Some parts of the plant may be indigestible and the primary consumer therefore egests, in the form of faeces, non-utilisable energy.

3. Any consumer does not eat all of any particular plant - roots for example may be left in the ground and these represent lost energy (Fig 2).

Fig 2. Energy transfer



Similarly, these losses are repeated at every successive trophic level and it is this loss of energy at each stage which results in declining numbers and biomass of organisms at each trophic level. In other words, it is the loss of energy at each stage which gives rise to pyramids of numbers and pyramids of biomass. All consumers are, however, entirely dependent on the green plants for their source of energy. Primary consumers are directly dependent and secondary and tertiary consumers are indirectly dependent on this initial capture of light energy.

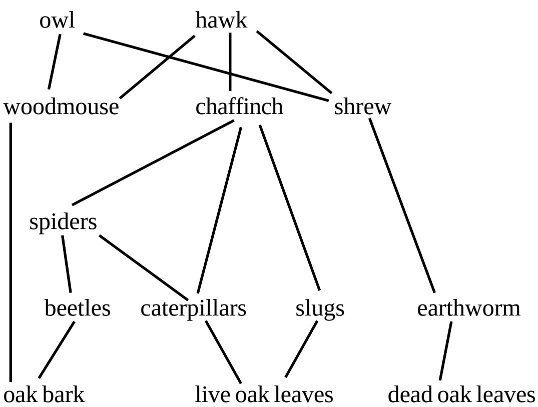
The energy contained in dead organisms or in faeces is utilised by organisms which make up a saprophytic food chain. Saprophytic organisms - which feed on dead organic material - often use extra-cellular digestion, that is, they secrete enzymes onto the food material and then attempt to reabsorb some of the products of digestion. Inevitably, some of the products of digestion - sugars and amino acids in solution, etc. - penetrate into the soil and may undergo further chemical transformation. Such nutrients may then become available for absorption by plant roots. Over a much longer time period however, the remains of dead plants and animals may accumulate, become compacted and eventually be transformed into fossil fuels; coal, oil and natural gas represent the fossilised remains of dead organisms and act as a long-term store of solar energy. During the 20th century, humans have spectacularly increased their extraction and combustion of such resources. Development of countries is inextricably linked to their increasing energy consumption.

Implications of energy flow

Loss of energy at each stage of a food chain - through respiration of the preceding organism, through faeces and through not all of the preceding organism being eaten, has important implications for humans in terms of food production systems. Quite simply, the longer the food chain, the more energy will be lost. So in terms of energy capture, it is more efficient for humans to try to obtain their energy requirements by eating plants than it is by eating animals. This is despite the fact that carnivores such as humans have a greater assimilation efficiency when consuming meat than when consuming vegetable matter (generally speaking, the closer the similarity between the tissues of the consumer and the tissues of the food it eats, the higher the assimilation efficiency). Secondly, it is important to appreciate that our food production systems based upon meat are heavily energy-subsidised - pesticides and fertilisers are made using fossil fuels and mechanisation requires similarly large inputs of fossil fuels. Since these are finite, i.e. they will run out, it is important that we do not become dependent on forms of food production which require a net energy input.

Practice questions

1. The diagram below shows part of a food web in an oak woodland.



(a) Identify:
- (i) a detritivorous primary consumer (1 mark)
- (ii) a tertiary consumer (1 mark)

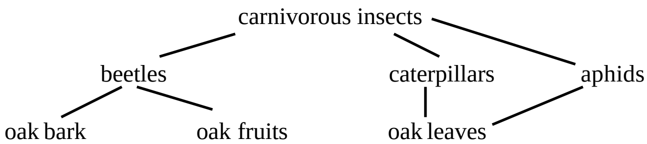
(b) Suggest how this community might be altered if the population of woodmice died out. (3 marks)

Limitations of ecological models

Food chains, food webs, pyramids of number, biomass and energy can be thought of as ecological models. Their limitations, summarised below, frequently appear on examination questions.

Food chains - Organisms do not usually feed on just one type of organism.

Food web - A series of interconnected food chains. More realistic but don't quantify the relative contribution of food sources. This is often tested in food web questions:

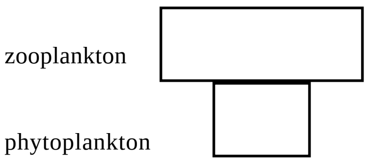


Q. Suggest how the population of beetles might be affected if the caterpillar population died out.

A. If caterpillars were a major dietary component of carnivorous insects then the number of beetles and/or aphids eaten might significantly increase. However, if caterpillars were only a minor component of the insects' diet then the number of beetles and/or aphids eaten might not alter very much. We cannot be sure because the food web does not tell us the relative importance of each part of the carnivorous insects' diet or anything about their feeding preferences.

Pyramids of numbers - Do not take into account the relative size of producers and consumers - one tree can support thousands of caterpillars, for example, so the pyramid is often inverted.

Pyramids of biomass - Overcome the problem of body size but do not take into account productivity. Consequently, they sometimes present a misleading picture. In exams, the most common example is an inverted pyramid of biomass for the English Channel.



Despite appearances, the biomass of zooplankton are not being supported in any sustainable way by a smaller biomass of phytoplankton - the pyramid does not show the **productivity** of the phytoplankton (i.e. the number of new phytoplankton the phytoplankton are producing).

Pyramids of productivity (or energy) - The most difficult to construct but always pyramidal! These show the amount of energy at, or the productivity of, each trophic level.

Answers

1. (a) (i) earthworm;
   (ii) chaffinch / owl / hawk;
   (b) owl / hawk population may decline;
   chaffinch / shrew population may decline because of increased predation;
   so less predation of primary consumers;

Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham. B18 6NF
 ISSN 1351-5136