Environmental Studies
FACT SHEET
www.curriculum-press.co.uk
Number 204

Energy flow through woodlands

In the exam, there are basically 5 types of questions on this topic. Questions ask you to:

1. Describe how plants obtain solar energy
2. Do simple calculations on energy flow between trophic levels and calculate efficiency and losses
3. Explain the terms GPP and NPP and perform simple calculations on these
4. Explain why focusing on energy flow is more useful than focusing on biomass
5. Explain how human activities e.g. deforestation alter natural energy flow

This Factsheet goes through each of these questions, focusing on deciduous woodlands and tropical forests but the principles apply to all other ecosystems.

Energy capture and flow

The general principle you must understand is the first law of thermodynamics: ***The law of conservation of energy***.

The total energy of an isolated system is constant; energy can be transformed from one form to another e.g. solar to chemical, but cannot be created or destroyed.

So, in the exam never write anything like " the leaves make energy" They don't; they **convert** solar energy into chemical energy (in a pretty inefficient way, as we will see).

Light energy is absorbed by chlorophyll in the leaves of tree and other plants. About 10% (but usually a lot less) of the available solar energy is converted into chemical energy via photosynthesis. The other 90+% is 'lost' because:

- It is the wrong wavelength to be absorbed
- It is reflected
- It is transmitted i.e. it passes straight through the leaves
- It cannot be converted into chemical energy because of other limiting factors e.g. the amount of carbon dioxide or water available

Of the 10% of solar energy that does get converted into chemical energy (in the form of e.g. ATP and glucose etc.), only 10% of that reaches the next trophic level i.e. the herbivores e.g. caterpillar. This is because:

- Not all of the leaf is eaten
- The leaves and the rest of the plant use the chemical energy for their respiration (respiration = the release of energy from food)
- Some energy is lost as heat

Only 10% of the energy in the caterpillar reaches the carnivores or omnivores in the next trophic level because:

- Only part of the caterpillar gets eaten
- The caterpillar uses some of the energy in respiration and during this process energy is lost as heat
- The caterpillar egests energy in the form of faeces
- The caterpillar loses energy via excretion (egestion and excretion are not the same thing). Egestion is the removal from the body of undigested food. Excretion is the removal from the body of the waste products of metabolism.
  Example: egestion = faeces, excretion = sweat

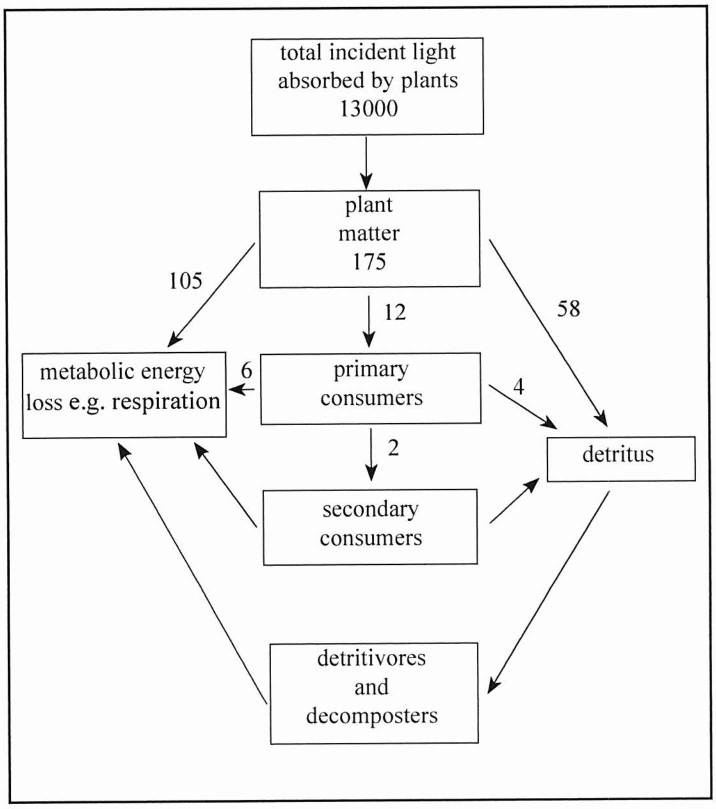
So, a blue tit eating the caterpillar is effectively getting 10% of 10% of 10% i.e.0.1% of the original solar energy.

This continues at each trophic level. Energy is effectively lost at each trophic level and this explains why most food chains have a maximum of 5 trophic levels – after that there isn't enough energy to sustain any further top carnivores.

Fig. 1 summarises this energy flow. The units are $kJm^{-2}yr^{-1}$ so they take into account:

1. The amount of energy in kilojoules
2. The area of land
3. The fact that the data was measured over a stated time period

Fig. 1 Energy flow through a woodland



Eventually, when leaves and animals die, they are broken down by detritivores and decomposers and this involves complex pathways in itself.

Definitions

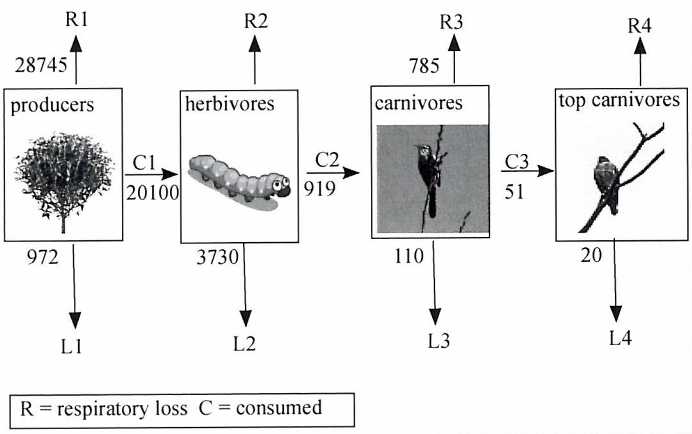
Detritivores: invertebrate animals that ingest and fragment bits of dead plants and animals. Examples include earthworms, woodlice, mites, springtails, millipedes and blowfly larvae.

Decomposers: organisms that colonise and break down the organic matter e.g. dead plants and animals, releasing sugars, amino acids and other organic molecules that can then be used by other organisms.
Examples include bacteria and fungi.

The 10% figure is approximate, it varies between ecosystems and within an ecosystem at different times of the year. Exam questions often give you some figures and you have to calculate missing values. Here is an example:

Typical Exam Question

The diagram shows the flow of energy ($kJm^{-2}yr^{-1}$) through deciduous woodland.



(a) Energy flow through the herbivores can be expressed as:
C1 = C2 +R2 + L2
(i) Calculate the respiratory loss by the herbivores (2)
(ii) Write the equation that represents energy flow through the carnivores (1)

(b) (i) Name two metabolic processes represented by L (2)
(ii) What happens to the energy lost in the form of L? (2)

Mark Scheme

(a) (i) 20100 = 919 + 3720 + R2;
R2 = 20100 – 919 – 3720 = 15461 $kJm^{-2}yr^{-1}$
(ii) C2 = R3 + L3 + C3;

(b) (i) death;
defaecation;
excretion;
(Any 2)
(ii) passed to decomposers / detritivores / saprotrophs;
respired / used / released by decomposers;
lost as heat;
(Any 2)

GPP and NPP

Gross primary production (GPP) is the rate at which the producers (usually green plants) in an ecosystem capture and store chemical energy as biomass in a given length of time.

Net primary production (NPP) is the amount of energy left from GPP after plant respiration and cell maintenance.

Some fraction of this fixed energy is used by primary producers for cellular respiration and maintenance of existing tissues.

So: GPP = NPP + R or NPP = GPP – R

The units of measurement for both GPP and NPP are:
mass of carbon per unit area per year ($g\ C\ m^{-2}\ yr^{-1}$).

In the exam, the calculation questions on this are usually simple e.g.

Question

The diagram below shows the amount of energy flowing through a food chain in an oak forest ($kJ\ m^{-1}\ yr^{-1}$).

incident sunlight energy 3×10^6
↓
trees and other plants NPP = 1.8×10^4 —1800→ caterpillars —100→ insectivorous birds

(a) Calculate the percentage of the incident energy which becomes available as the net primary production (NPP) of trees. Show your working.

(b) Explain why the biomass of insectivorous birds is usually a fraction of the biomass of caterpillars

Mark scheme

(a) $(1.8 \times 10^4 \div 3 \times 10^6) \times 100 = (18\ 000 \div 3\ 000\ 000) \times 100$;
= 0.006 × 100 = 0.6%;(2)

(b) Energy has been lost;
Via caterpillar respiration/as heat/egestion/excretion
So less biomass can be supported; (2)

The greatest loss of energy between trophic levels is usually between tropic level 1 (the plants) and trophic level 2 (the herbivores).

This is because a large proportion of the plant is inedible or indigestible e.g. tissues such as xylem, woody tissue and lignin. So the energy contained in these is unavailable.

Energy flow disruption by slash and burn

Slash and burn farming is a form of shifting agriculture where the natural vegetation e.g. rainforest is cut down and burned so that the land can be used for agriculture. For about two years the fertile ash provides nutrients for the crops, but after that all of the nutrients have been used and none returned via leaf litter. The plot becomes infertile and the farmer moves to a new fresh plot and this process is repeated over and over again.

https://commons.wikimedia.org/wiki/File:Slash_And_Burn,_Isalo_National_Park.jpg?uselang=en-gb Antony Stanley

So how does slash and burn affect the natural flow of energy?

- Interception of sunlight energy is hugely reduced – the trees and the various layers of the vegetation have been lost
- NPP is reduced
- The quantity of biomass, hence energy being supplied to detritivores and decomposers is reduced

Slash and burn farming is unsustainable. To make it even remotely sustainable the cleared land would have to be left for decades to allow secondary forest to become established, increasing absorption of incident light, increasing both GPP and NPP and protecting the soil from rainfall erosion.

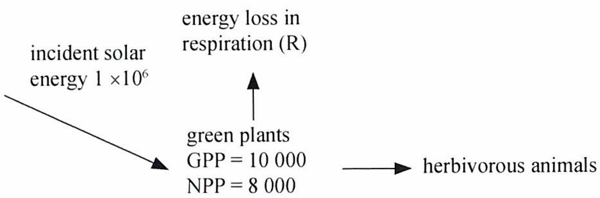
Human activity often diverts the flow of energy:

- Deforestation and urbanisation decrease the amount of energy absorbed by plants.
- Pesticides reduce the amount of energy flowing into any detritivores that are killed.
- Fertilisers increase crop growth, increasing the amount of incident energy absorbed by the crop.

Practice Questions

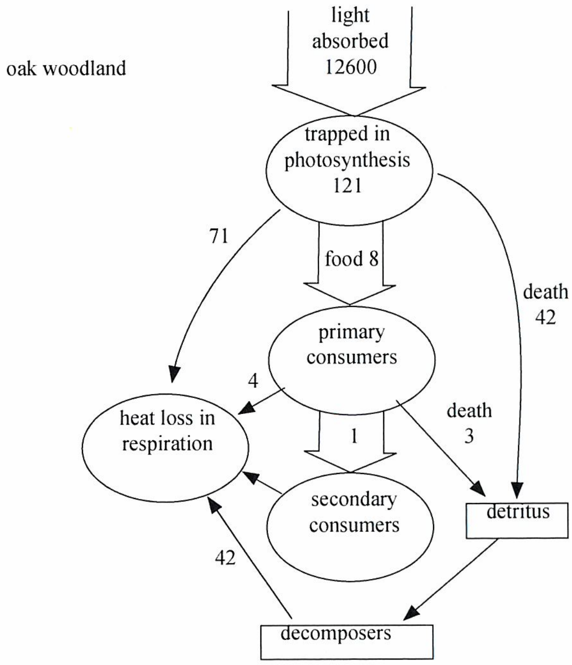
1. (a) (i) Explain why only a small percentage of the light energy falling onto a leaf is converted into chemical energy. **(2)**
   (ii) Explain why only 10% of the energy locked up in the secondary consumers is transferred to the tertiary consumers. **(2)**

2. (a) The diagram shows energy flow in part of a woodland ((kJ m^{-1} yr^{-1}).



   (i) Calculate the energy loss in respiration (R) by green plants (2).
   (ii) Calculate the percentage of the incident solar energy that becomes incorporated into the net primary production (NPP) (2)

3. The diagram shows the flow of energy through oak woodland measured as kJ m^{-2} day^{-1}.



   (a) Calculate the efficiency with which solar energy is trapped by the forest plants (2).
   (b) In terms of energy flow, suggest why there appear to be no tertiary consumers in the woodland (2).
   (c) Explain why data on energy flow is considered more useful than data on biomass (2)

Mark schemes

1 (a) (i) Reflection;
Transmission;
Wavelength not used in photosynthesis;
(ii) Energy lost as heat;
Energy lost through defaecation;
Energy lost through excretion;
Not all of any secondary consumers eaten;

2. (i) R = GPP – NPP;
R = 10000 – 8000 = 2000 kJ m^{-1} yr^{-1};
(ii) (8000 ÷ 1×10^6) × 100; = 0.8%;

3. (a) (121÷12600 × 100; = 0-9/0-96%;
(b) Energy lost at each trophic level;
Respiration/egestion/excretion/not absorbed or used;
Insufficient energy left to sustain organisms at higher level;
(c) energy flow takes account of time / cancels out fluctuations / biomass measured at only one time;
biomass varies seasonally;
nature of biomass / organic material varies/ may not provide useful data on productivity;

Acknowledgments: This Factsheet was researched and written by **Kevin Byrne**
Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU
Environmental Studies Factsheets may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. **ISSN 1351-5136**