leguminous crops with root nodules containing nitrogen-fixing bacteria. These plants enrich the soil with nitrogen when they decompose. The soil condition also affects the nitrogen cycle. If it becomes waterlogged near the surface, most bacteria are unable to break down detritus because of lack of oxygen but certain bacteria can. Unfortunately they release the nitrogen as gas back into the air. This is called denitrification. Excessive flow of rainwater through a porous soil, such as sandy soil, will wash away the nitrates into rivers, lakes and then the sea. This is called leaching and can lead to eutrophication.

To do

Copy the diagram of the nitrogen cycle and add these terms to it:

nitrogen fixation, nitrification, denitrification, decomposition, assimilation.

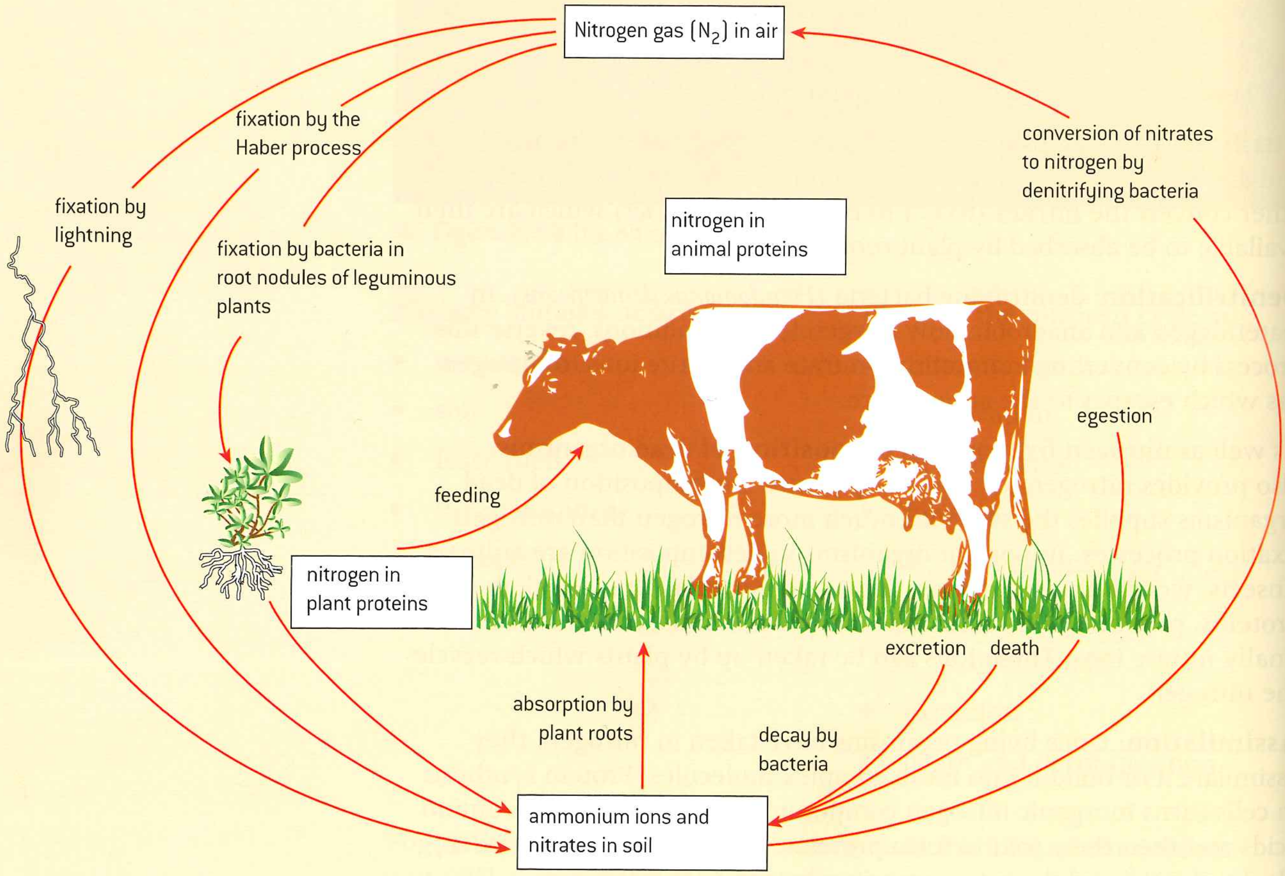
Copy and complete:

Nitrogen fixation is:

Nitrification is:

Denitrification is:

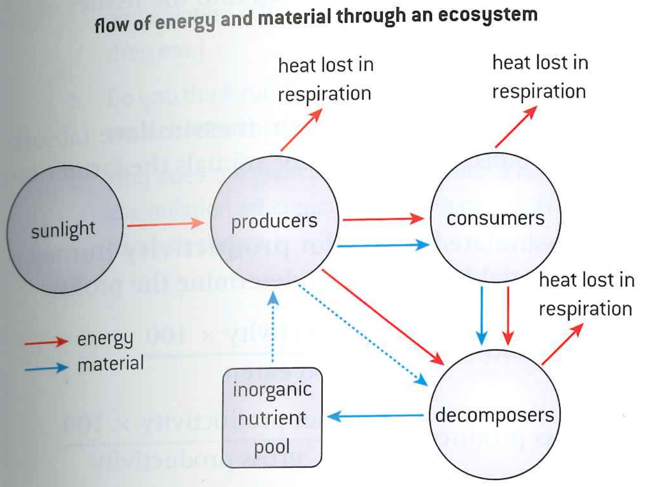
Assimilation (or protein formation) is:



▲ **Figure 2.3.9** The nitrogen cycle

Energy flow diagrams

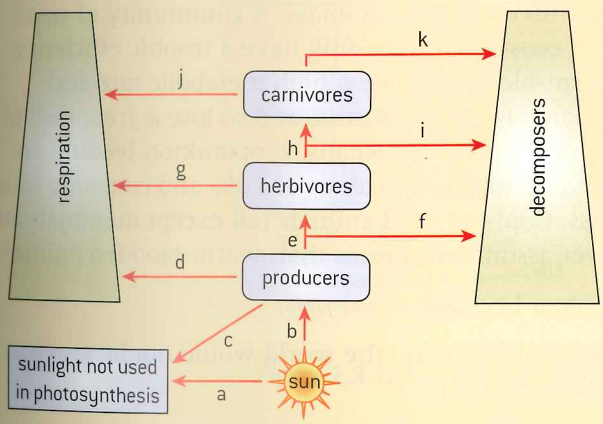
Energy flow diagrams allow easy comparison of various ecosystems. These show the energy entering and leaving each trophic level. Energy flow diagrams also show loss of energy through respiration and transfer of material as energy to the decomposer food chain.



▲ **Figure 2.3.10** Generalized energy flow diagram through an ecosystem

To do

The diagram below shows the flow of energy through a food web, and should be used for the three questions (right).



▲ **Figure 2.3.11** Generalized energy flow diagram through a food web

1 Gross primary productivity (GPP) is

A. b – c.

B. b – a.

C. b.

D. b – c – d. [1]

2 Net primary productivity (NPP) is

A. b – c – d.

B. d + e + f.

C. e.

D. e – d. [1]

3 The net productivity for the consumer community is

A. e + h.

B. e + h – g – j – k – i.

C. e – g – j.

D. e – g – j – i – k. [1]

There are many different ways to draw energy flow diagrams and you need to be able to interpret these. Some examples are given in the next pages.

Assimilation and productivity efficiencies

There are two quantities that we need to know to establish these efficiencies.

1. What proportion of the NPP from one trophic level is assimilated by the next?
2. How much of this assimilated material is turned into the tissues of the organism and how much is respired?

For an animal raised for meat these questions are:

1. How much of the grass that an animal eats can it **assimilate** (absorb into its body)? This will determine how many animals the farmer can put in a field.
2. How much of what is assimilated is used for **productivity** (turned into meat)? On a commercial farm this will determine the profits.

$$\text{Efficiency of assimilation} = \frac{\text{gross productivity} \times 100}{\text{food eaten}}$$

$$\text{Efficiency of biomass productivity} = \frac{\text{net productivity} \times 100}{\text{gross productivity}}$$

Trophic efficiency

The efficiency of transfer from one trophic level to the next, eg the ratio of secondary productivity to primary productivity consumed, is considered, on average, to be about 10%. As always, things are not quite as straightforward as they at first appear. While the 10% rule is a generalization and a helpful aid to our understanding of energy flow, there are considerable variations. Trophic efficiencies generally range from 5% to 20%, ie only 5% to 20% of primary producer biomass consumed is converted into consumer biomass. A community of small mammals in a grassland ecosystem may only have a trophic efficiency of 0.1% as they are warm-blooded, have a high metabolic rate and large surface area compared to their volume, and so lose a great deal of energy in respiration and heat. In the oceans, zooplankton feeding on phytoplankton may have a trophic efficiency of 20% and consume most of the producer biomass. Cold-blooded animals (all except mammals and birds) have much slower assimilation rates than warm-blooded animals.

Trophic inefficiencies occur because:

- Not everything is eaten (if it were, the world would not be green as all plants would be consumed).
- Digestion is inefficient (food is lost in feces because the digestive system cannot extract all the energy from it).
- Heat is lost in respiration.
- Some energy assimilated is used in reproduction and other life processes.

Energy budgets

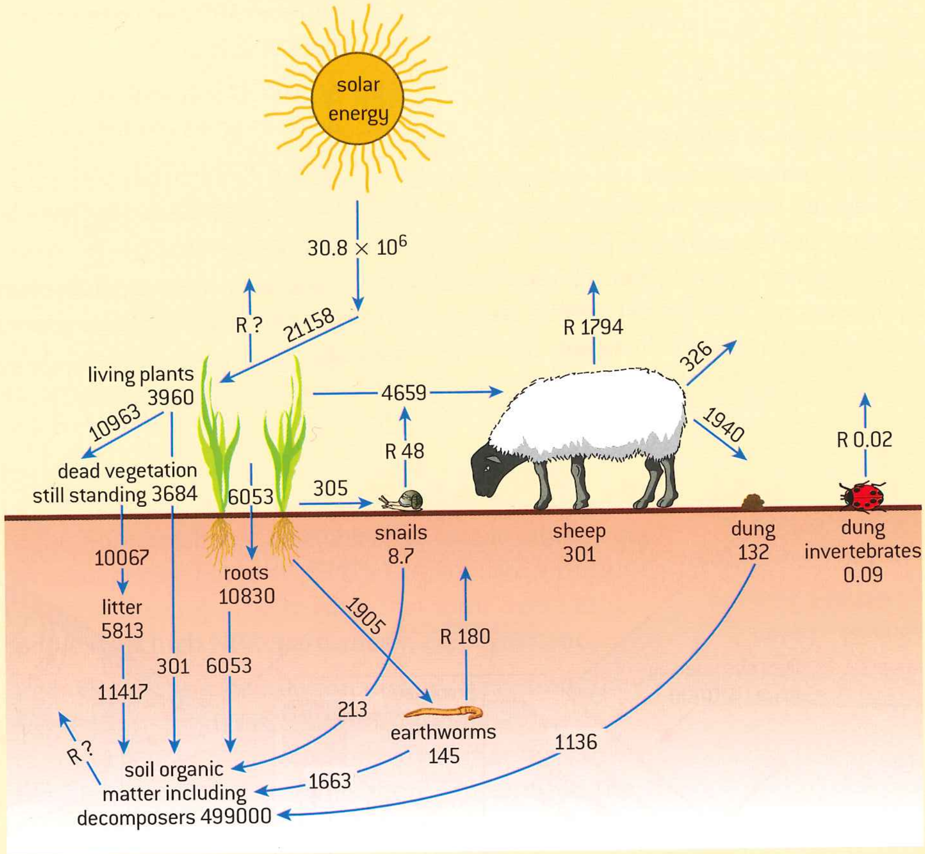
For an individual animal or population, we can measure the quantities of energy entering, staying within and leaving the animal or population. This is its **energy budget**. It can be measured in the laboratory for a population of silk worms or locusts and it is useful for farmers to know what stocking rate of animals per hectare they can use.

To do

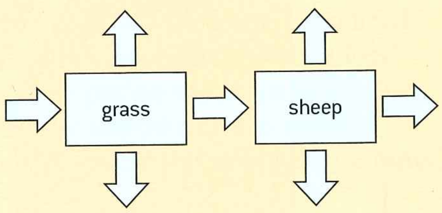
1. Consider the assimilation efficiencies in the table on the right.
   a. Why do carnivores have a relatively high assimilation efficiency. (Think about the food they eat.)
   b. Do you think ruminant herbivores would be at the top or bottom of the range for herbivores? Why?
   c. Why does the giant panda have such a low assimilation efficiency? (Hint: its diet is mainly bamboo shoots.)

Organism	Assimilation efficiency
Carnivore	90%
Insectivore	70–80%
Herbivore	30–60%
Zooplankton feeding on phytoplankton	50–90%
Giant panda	20%

2. Copy figure 2.3.13 and add the energy storages and transfers in figure 2.3.12.



▲ **Figure 2.3.12** The energy budget in a sheep-grazed ecosystem



▲ **Figure 2.3.13**

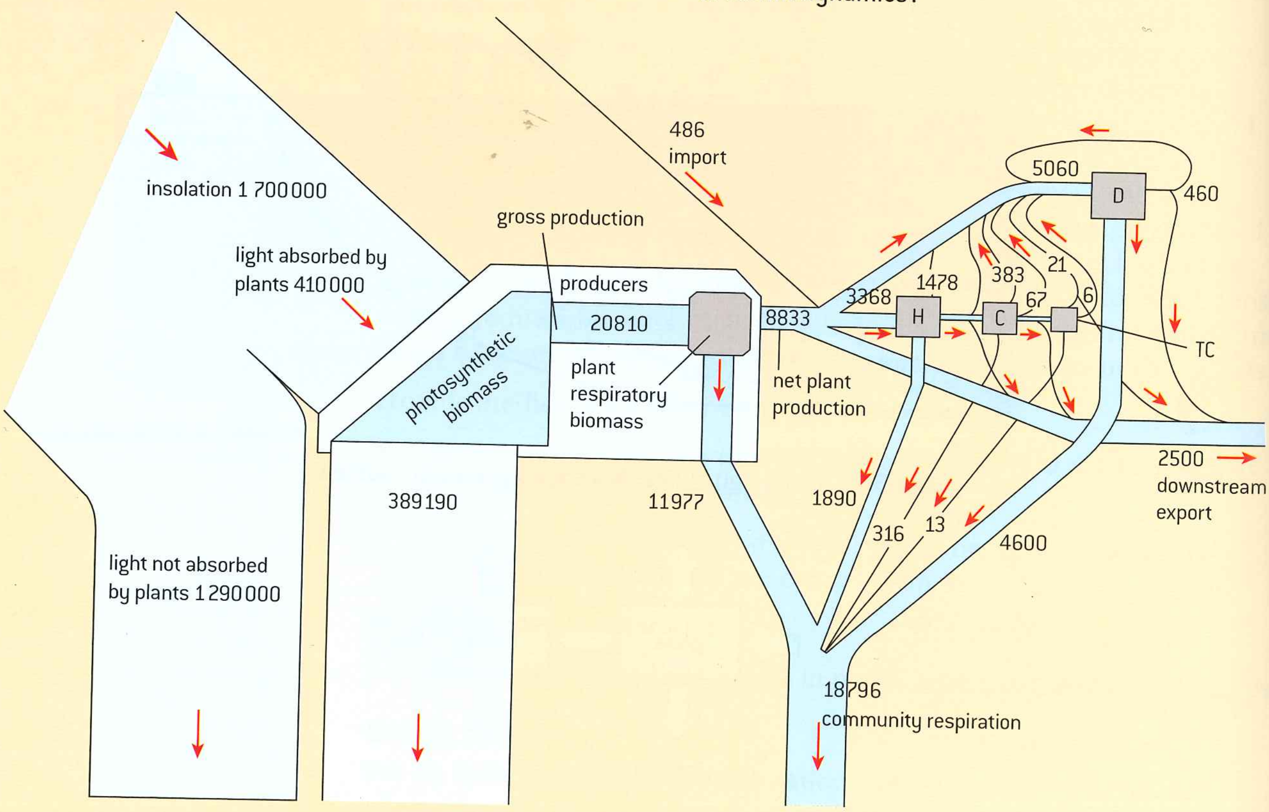
To do

The classical energy flow example

Silver Springs, in central Florida is famous amongst ecologists as the place where Howard T. Odum researched energy flow in the ecosystem in the 1950s. Odum (1924–2002) was a pioneer ecologist working on ecological energetics. This was the first time an energy budget measurement was attempted when Odum measured primary productivity and losses by respiration. (Later, near the end of a long and illustrious career, he and David Scienceman developed the concept of **emergy** (embodied energy) which is a measure of the quality and type of energy and matter that go into making an organism.)

Figure 2.3.14 shows the energy flows and biomass stores measured by Odum at Silver Springs. This simple community consists of algae and duckweed (producers); tadpoles, shrimps and insect larvae (herbivores); water beetles and frogs (first carnivores); small fish (top consumers); and bacteria, bivalves and snails (decomposers and detritivores). Dead leaves also fall into the water and spring water flows out, exporting some detritus.

1. Why does the width of the energy flow bands become progressively narrower as energy flows through the ecosystem?
2. Suggest an explanation for the limit on the number of trophic levels to four or five at most in a community.
3. How is the energy transferred between each trophic level?
4. Insolation (light) striking leaves is 1,700,000 units but only 410,000 are absorbed. What happens to the unabsorbed light energy?
5. A further 389,190 units escapes from producers as heat. Why is this?
6. Account (mathematically) for the difference between gross and net primary productivity.
7. Draw a productivity pyramid from the data given.
8. Would it be possible to draw a biomass pyramid from the data given?
9. Does the model support the first law of thermodynamics? Show your calculations.
10. How does the diagram demonstrate the second law of thermodynamics?



▲ **Figure 2.3.14** The energy flow values in Silver Springs community. Units kcal m^{-2} yr^{-1} (1kcal = 4.2 J)

Human activities and ecosystems

A process, effect or activity derived from humans is known as **anthropogenic ('anthro' meaning human)**. The enhanced greenhouse effect is anthropogenic. Do not confuse this with anthropomorphic which is giving human characteristics to other animals, plants or inanimate objects, eg your doll or your pets.

The concept of energy subsidy

Generally, when humans have an influence on an ecosystem, be it farming or living within it, we tend to simplify it and make it less diverse. Usually, this is on purpose. We cut down forest to grow crops and often this is just one species, eg wheat. So the complex food web that may have been there in a deciduous temperate forest becomes:

wheat ⟶ human

or

improved pasture grasses ⟶ cattle ⟶ human

Much of what we do in agriculture is also aimed at keeping things simple – killing pests and getting rid of weeds as these either eat or compete with the crops we want. Our aim is to maximize the NPP of the organisms we grow to maximize our profit. What happens is that we have to become ever more sophisticated in our farming practices – agribusiness – so we use artificial means to maintain the system. The Green Revolution which brought improved varieties of rice and other crops also brought the need to buy fertilizers for them or pesticides to kill the pests to which they were susceptible.

All farming practices require an **energy subsidy** which is the additional energy that we have to put into the system above that which comes from the Sun's energy. It may be the human labour, animal labour or machines using fuel to power the tractors and plows, pump water for cattle, make fertilizers and other chemicals, transport the crop. The result is that some agricultural systems are very productive with high NPP, particularly, eg, sugar cane.

As humans lived in larger groups and population density increased, they needed more food so farming methods became more sophisticated and used more energy. The advantage of an energy subsidy is that we can feed more people because food production seems more efficient but the energy has to come from somewhere (first law of thermodynamics). As communities become more complex, the energy subsidy increases. Hunter-gatherers have to add little energy to the system apart from their own work. Subsistence farming may involve draught animals, wind-power or water-power to irrigate or grind corn. All these are subsidized by human effort. Commercial farming now involves major use of fossil fuels to power machines, make chemicals to put on the crops or produce feedstuffs for animals. It is estimated that we use 50 times as much energy in MEDCs as a hunter-gatherer society and it is rising all the time.

Energy: yield ratio

In economic terms, we can look at a farming system as inputs and outputs or costs and profits. So we can look at energy in and energy out in the form of food. It seems that as agriculture has become more sophisticated, the ratio goes down. A simple slash and burn type agriculture (when land is cleared in the rainforest and then a variety of crops grown by a subsistence farmer) may have an energy:yield ratio of

Key term

Maximum sustainable yield (MSY) (see also 4.3) is the largest crop or catch that can be taken from the stock of a species (eg a forest, a shoal of fish) without depleting the stock. Taken away is the increase in production of the stock while leaving the stock to reproduce again. It is often used in managing fisheries.

The MSY is equivalent to the net primary or net secondary productivity of a system.

Practical Work

* Measure the GPP and NPP in a local ecosystem.
* Investigate the biomass in a local food chain.
* Design an experiment to measure productivity in different ecosystems.

To do

1. What are the two main reasons why there has been an increase in the impact of human activities on the environment over time?
2. Write down the three trends that can be seen in relation to the impact of human activities over time on ecosystems.

1:30 or 40 (30–40 units of food energy for each one unit of input energy as work). With increasing input of energy, this could reduce to 10:1 for battery chicken or egg production, so far more energy is put in to the system than taken out. But the important thing is that the energy is in the form of high energy foods – concentrated energy such as protein and meat, not lower energy cereals. We are producing high energy foodstuffs.

The issue to remember is that energy has to keep flowing through ecosystems whether natural or influenced by humans. If it does not, the system alters rapidly. Blocking sunlight from reaching a plant stops photosynthesis and the plant dies. Stopping the energy subsidy to agriculture will result in chaos. In a natural ecosystem, the large number and variety of food chains and energy paths mean the system is complex and less likely to fail completely. If one species goes, others can take its role. The system is resilient. If there is only one species in an ecological niche, eg wheat, its failure can have a bigger impact.

To do

The data refer to carbon (in biomass) flows in a freshwater system at 40° N latitude:

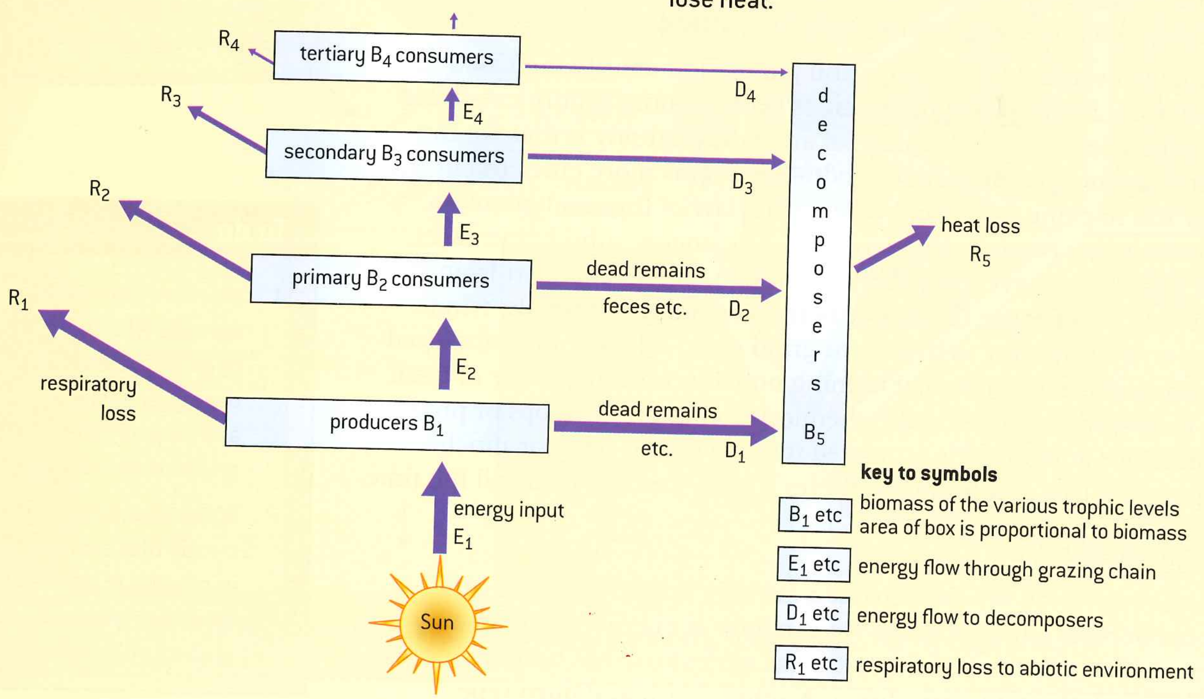
	$g\,C\,m^{-2}\,yr^{-1}$
Gross productivity of phytoplankton	132
Respiratory loss by phytoplankton	35
Phytoplankton eaten by zooplankton	31
Fecal loss by zooplankton	6
Respiratory loss by zooplankton	12

From the data, write down word equations and calculate:

a. net productivity of phytoplankton
b. gross productivity of zooplankton
c. net productivity of zooplankton
d. % assimilation of zooplankton
e. % productivity of zooplankton.

Here are two more energy flow diagrams.

a. For ecosystem I, copy and draw a rectangle on the diagram to show the ecosystem boundary.
b. Explain why the storage boxes reduce in size as you go up the food chain.
c. Name three decomposers and explain how they lose heat.



▲ **Figure 2.3.15** Energy flow diagram of an ecosystem I

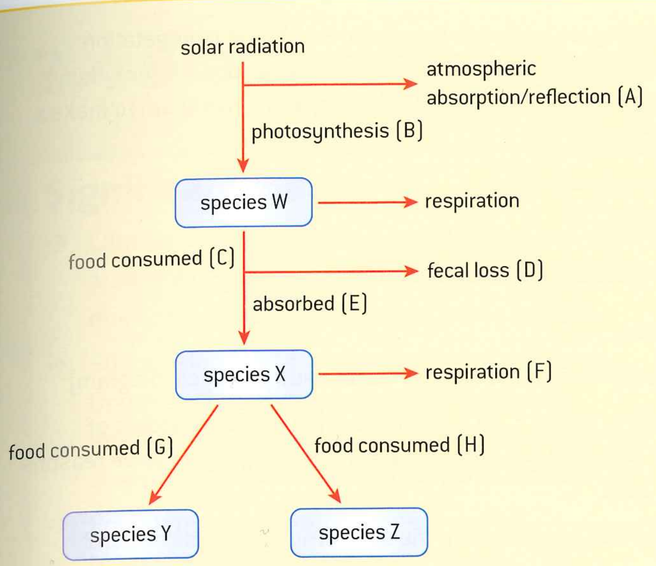


Figure 2.3.16 Energy flow diagram of an ecosystem II

d. For ecosystem II, identify from the diagram the letter(s) referring to the following energy flow processes and explain what happens to this energy at each stage as it passes through the ecosphere:

i. loss of radiation through reflection and absorption

ii. conversion of light to chemical energy in biomass

iii. loss of chemical energy from one trophic level to another

iv. efficiencies of transfer

v. overall conversion of light to heat energy by an ecosystem

vi. re-radiation of heat energy to atmosphere.

To do

Nutrient cycling in terrestrial ecosystems

Copy, fill the gaps and delete incorrect options in the paragraph below.

All living organisms need elements such as _____ and _____. These are needed to produce worms/minerals/growth/organic material. The availability of such elements is finite – we cannot increase the amount. The plants take up the nutrients from the soils, and once they have been used are passed on to the carnivores/herbivores/photosynthesizers/producers and then the _____ which feed upon them. As organisms die, they _____ and nutrients are returned to the system. As for all systems, there are inputs, _____, storages and _____. Nutrients are stored in _____ main compartments: the biomass (total mass of living organisms), the soil and the _____ (the surface layer of vegetation which may eventually become humus).

A model of the nutrient cycle is given below. Add the name of each of the transfers of nutrients to the boxes.

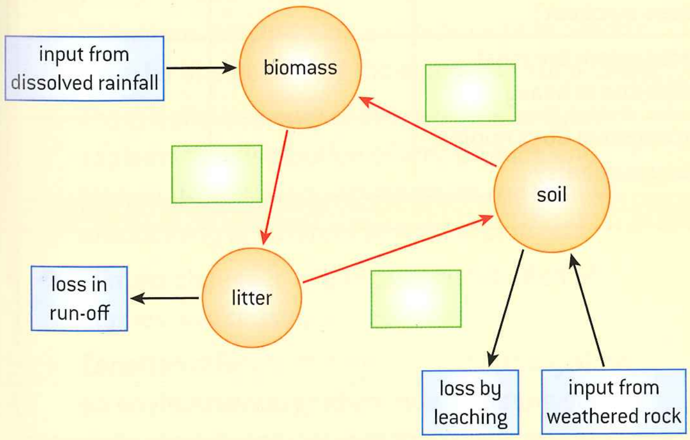
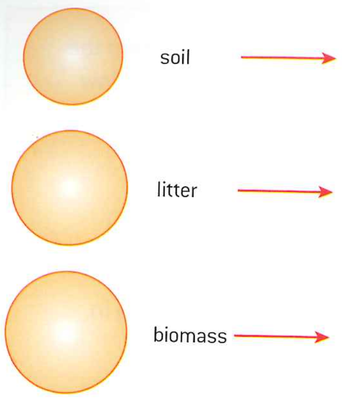
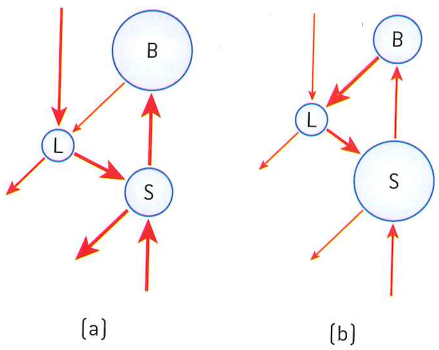


Figure 2.3.17 Gersmehl's model



▲ **Figure 2.3.18** Making Gersmehl's model



▲ **Figure 2.3.19** Gersmehl's models for two different ecosystems (see box to right)

The nutrient cycle varies according to the climate and type of vegetation. The size of each of the stores and size of the transfer can be different. Using the symbols given left (no re-sizing needed), copy and move them to make a nutrient cycle diagram for

1. a deciduous woodland and
2. a tropical rainforest.

Explain the size of the BIOMASS, SOIL and LITTER stores for each.

Grassland ecosystem

(Redraw and resize the boxes to make the correct nutrient cycle diagram)

1. In the ecosystem in figure 2.3.17, there are relatively large stores of nutrients in the litter and soil compared to living things. Give three reasons why this is the case.
2. What is the main nutrient flow from the soil? Why does this happen?
3. Is transport of minerals from one soil layer to another a transfer or a transformation process?
4. Look at the two nutrient models left, a tropical rainforest and a continental grassland (prairie) ecosystem. Label each with its respective ecosystem name.
5. Copy and complete the table of comparisons between the two ecosystems:

Comparison	Ecosystem	Explanation
Which ecosystem stores most nutrients in biomass?		
Which ecosystem has most undecomposed detritus?		
Which ecosystem has least humus?		
In which ecosystem is plant uptake of nutrients greater?		
In which ecosystem is decomposition slower?		
Which ecosystem loses nutrients from biomass quickest?		
In which ecosystem are most nutrients lost due to heavy rain?		
In which ecosystem does rainfall supply many nutrients?		

2.4 Biomes, zonation and succession

Significant ideas:

- Climate determines the type of biome in a given area although individual ecosystems may vary due to many local abiotic and biotic factors.
- Succession leads to climax communities that may vary due to random events and interactions over time. This leads to a pattern of alternative stable states for a given ecosystem.
- Ecosystem stability, succession and biodiversity are intrinsically linked.

Applications and skills:

- **Explain** the distributions, structure, biodiversity and relative productivity of contrasting biomes.
- **Analyse** data for a range of biomes.
- **Discuss** the impact of climate change on biomes.
- **Describe** the process of succession in a named example.
- **Explain** the general patterns of change in communities undergoing succession.
- **Discuss** the factors which could lead to alternative stable states in an ecosystem.
- **Discuss** the link between ecosystem stability, succession, diversity and human activity.
- **Distinguish** the roles of r and K selected species in succession.
- **Interpret** models or graphs related to succession and zonation.

Knowledge and understanding:

- **Biomes** are collections of ecosystems sharing similar climatic conditions which can be grouped into five major classes – aquatic, forest, grassland, desert and tundra. Each of these classes will have characteristic limiting factors, productivity and biodiversity.
- Insolation, precipitation and temperature are the main factors governing the distribution of biomes.
- The **tricellular model** of atmospheric circulation explains the distribution of precipitation and temperature influencing structure and relative productivity of different terrestrial biomes.
- Climate change is altering the distribution of biomes and causing biome shifts.
- **Zonation** refers to changes in community along an environmental gradient due to factors such as changes in altitude, latitude, tidal level or distance from shore (coverage by water).
- **Succession** is the process of change over time in an ecosystem involving pioneer, intermediate and climax communities.
- During succession the patterns of energy flow, gross and net productivity, diversity and mineral cycling change over time.
- Greater habitat diversity leads to greater species and genetic diversity.
- **r and K strategist species** have reproductive strategies that are better adapted to pioneer and climax communities respectively.
- In early stages of succession, gross productivity is low due to the unfavourable initial conditions and low density of producers. The proportion of energy