1.1.1 Outline the concept and characteristics of systems

Glossary

concept an idea of how something is

example explains a particular problem or issue

Subject vocabulary

system a collection of parts and the relationships between them, which together make a whole

input the movement into something

output the movement out from something

storage where something is kept

flow movement from one place to another

process an action or series of actions that achieve a particular result; in systems, these can be transfers or transformations

feedback mechanism where the results of a process influence the input of the process

systems method an approach where component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation

systems diagram a drawing of a system that uses boxes as storages and arrows as flows

biomass living matter, made from biological molecules

transfer a process involving a change of location within the system, but no change in state

transformation a process that leads to the formation of new products or involves a change in state

Synonyms

characteristics .... features

matter .... substance/material

What is a system?

A **system** is made up of separate parts which are linked together and influence each other.

What are the characteristics of a system?

All systems have **inputs** and **outputs**. According to the system, these can be inputs and outputs of energy, **matter**, or information. All systems also have **storages**, **flows**, **processes**, and **feedback mechanisms**. The **systems method** allows different subjects, such as ESS, Economics, and Sociology, to be looked at in the same way and for connections to be made between them.

Systems can be shown as diagrams. Figure 1.1 shows a **systems diagram** containing:

- a box that shows storages – in this **example**, tree **biomass**
- arrows that show flows – the tree's inputs and outputs
- processes can be shown on the arrows to indicate which **transfers** and **transformations** are taking place.

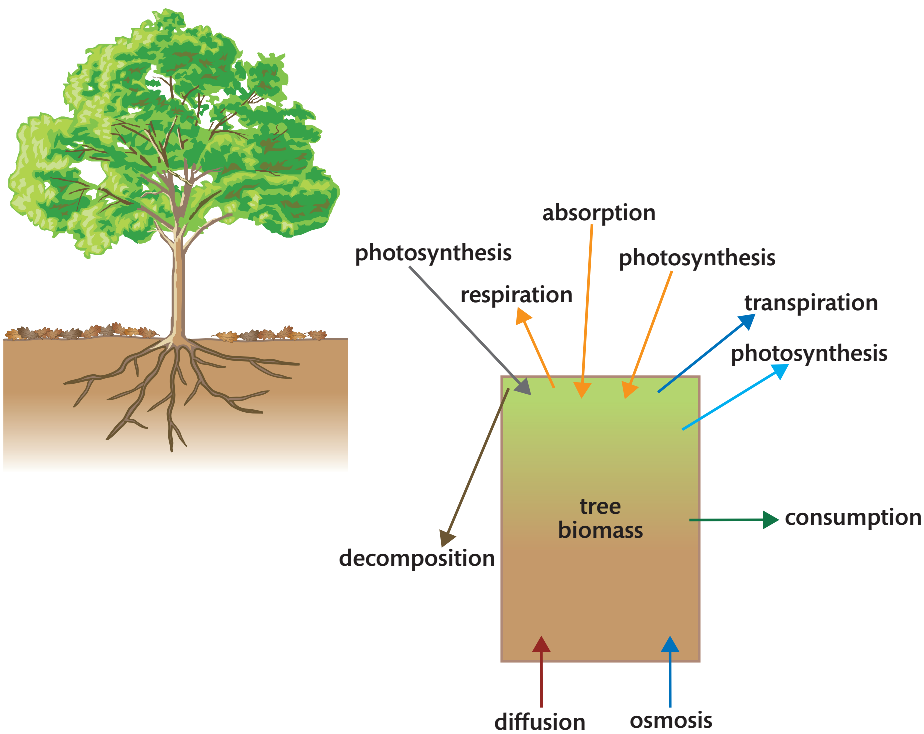

Figure 1.1 *A tree drawn using the systems method (diagram on the right).*

All systems diagrams are shown in the same way, with boxes representing storages, arrows representing flows, and processes indicated on the arrows.

Comparing different systems

Different subjects will contain different systems, but there are similarities between all systems. Examples of different subjects are ecology, economics, sociology, and philosophy. This table shows how the **systems concept** can be applied to different systems:

	Ecosystem	Economic system	Social system	Value system
Flows	Energy and matter	Production, income, and spending	Information, ideas, and people	Culture and society, decisions and actions
Storages	Biomass, the atmosphere, and soil	Banks, goods, and services	Ideas, beliefs, and customs	Personal value systems

Systems can be looked at in two **contrasting** ways. A **reductionist approach** looks at the individual parts of a system. This approach is usually used in traditional scientific investigations. A **holistic** approach looks at how the parts of a system work together as a whole. This approach is usually used in modern ecological investigations.

What are the advantages of using the systems method?

The advantage of using the systems method is that diagrams can be used to show how the **components** within the whole system **relate** to one another. Because the same method is used in all subjects, comparisons and links can be made between different academic subjects, as shown in the table above.

Hints for success: Use the box and arrow method shown in Figure 1.1 to draw a systems diagram. Do not draw pictures: for example, do not draw a tree.

Subject vocabulary

systems concept the idea that something can be looked at as a collection of parts that interact and are interdependent on each other

reductionist dividing a system into parts, each of which can be studied separately

holistic looking at a system as a whole, rather than as individual parts

Glossary

contrasting where there are differences between two or more things

component one or several parts which together make up a whole system

Synonyms

approach.............. method

relate.................. connect

1.1.2 Apply the systems concept on a range of scales

Model sentence: Ecosystems provide a good example of how systems can be applied to a range of scales.

Ecosystems can be any size, from small-scale to **global**. A forest contains many small-scale ecosystems, such as the species that live in **bromeliads** that are found towards the tops of the trees in tropical rainforests. The forest itself can also be seen as an ecosystem. The same type of forest ecosystem may be found in many different countries with the same **climatic** conditions. When an ecosystem is looked at on a global scale it is called a **biome**.

The following table shows a range of scales for different systems:

Scale	Ecosystem	Economic system	Social system	Political system
Small ↓	Local ecosystem	Home economy	Community	Band
	Biome	Market economy	Nationhood	Tribe, chiefdom
Global	The Earth	Global economy	Global society	Nation state

Model sentence: At the largest scale, the Earth and its atmosphere can be viewed as an ecosystem. This idea is central to the Gaia hypothesis.

A **model** can be made that shows how the Gaia hypothesis works:

Daisyworld

Daisyworld is a model for the Gaia hypothesis. Daisyworld shows how the Gaia hypothesis could control life on Earth. The only plants on Daisyworld are black and white **daisies**; the rest of the surface is bare. The temperature of Daisyworld is controlled by how much sunlight is **absorbed** and how much sunlight is **reflected** by the daisies. If the temperature of Daisyworld increases, then white daisies survive and reproduce because they can keep cool by reflecting the Sun's energy. Daisyworld cools down following the growth of white daisies. As it cools the black daisies now have an advantage as they absorb more heat. There will now be large numbers of black daisies which will absorb the Sun's energy and warm the planet. The **cycle** then repeats itself. Over time, the temperature of the planet reaches **equilibrium**. In this way, the temperature of the planet controls itself through **negative feedback**.

Glossary

concept an idea of how something is

example explains a particular problem or issue

scale a range of things from the smallest to the largest

global including the whole of the planet

bromeliad tropical American plants of the family Bromeliaceae; they have long stiff leaves and colourful flowers

climatic relating to rainfall, sunshine, humidity, wind, and temperature

daisy a flower, usually with white petals and a yellow centre

cycle a series of events that are regularly repeated in the same order

Subject vocabulary

ecosystem a community of organisms that depend on each other and the environment they live in

system a collection of parts and the relationships between them, which together make a whole

biome a collection of ecosystems sharing similar climatic conditions

Gaia hypothesis compares the Earth to a living organism in which feedback mechanisms maintain equilibrium

model a simplified description designed to show the structure of a system and how it works

equilibrium a state of balance among the parts of a system

negative feedback feedback that counteracts any change away from equilibrium. This form of feedback contributes to stability

Synonyms

range .... a variety of things

absorb .... take in

reflect .... send back

1.1.3 Define the terms *open system*, *closed system* and *isolated system*

Model sentence: An open system can be defined as a system that exchanges both matter and energy with its surroundings.

An example of an open system is an **ecosystem**, such as a lake.

Model sentence: A closed system can be defined as a system that exchanges energy, but not matter, with its surroundings.

An example of a closed system is the Earth.

Model sentence: An isolated system can be defined as a system that does not exchange matter or energy with its surroundings.

An example of an isolated system is the Universe.

Model sentence: The following figure summarizes the differences between open, closed, and isolated systems:

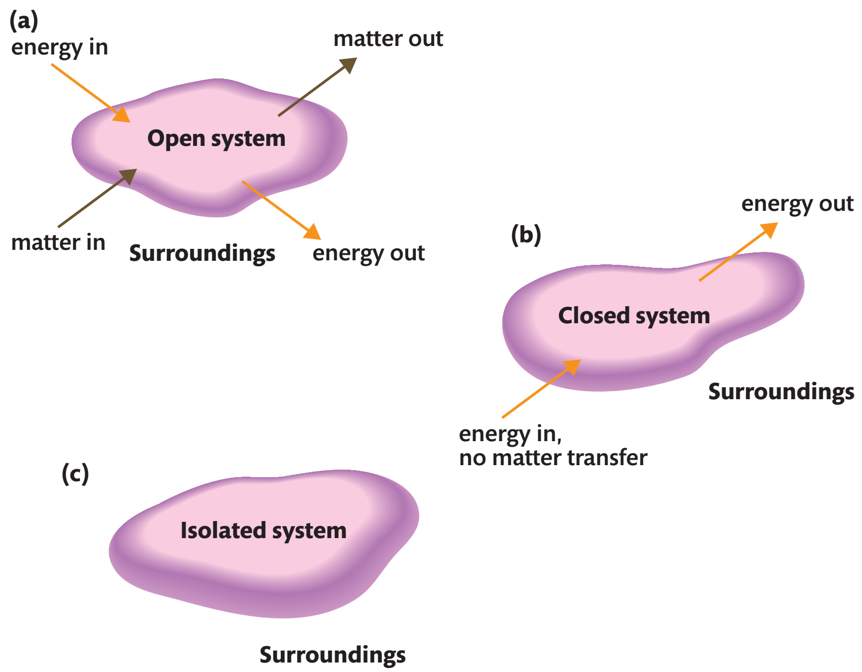

Figure 1.2 *The exchange of matter and energy across the boundary of different systems. (a) Open systems exchange both energy and matter; (b) closed systems exchange only energy; and (c) isolated systems exchange neither.*

Subject vocabulary

open system a system that exchanges both matter and energy with its surroundings

ecosystem a community of organisms that depend on each other and the environment they live in

closed system a system that exchanges energy but not matter with its surroundings

isolated system a system that does not exchange matter or energy with its surroundings

Glossary

surroundings everything that is near or around something

Synonyms

matter .... substance/ material

1.1.4 Describe how the first and second laws of thermodynamics are relevant to environmental systems

The behaviour of energy in **systems** is directly influenced by the laws of **thermodynamics**.

The first law of thermodynamics

The **first law of thermodynamics** states that energy cannot be created or destroyed: it can only be changed from one form into another. The first law of thermodynamics is known as the law of **conservation** of energy. This means that the total energy in any system is **constant** and all that can happen is that energy can change form.

The second law of thermodynamics

The **second law of thermodynamics** states that the **transfer** of energy through a system is inefficient and that energy is **transformed** into heat. This is shown in the following figure:

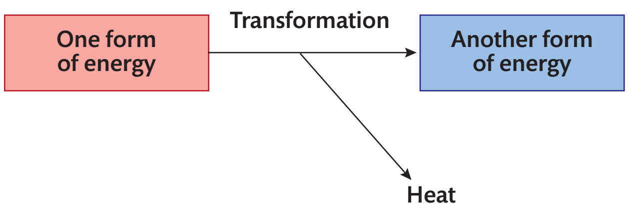

Figure 1.3 *The second law of thermodynamics states that some energy is converted into heat when energy is transformed from one form to another.*

The second law of thermodynamics explains that, in systems, energy goes from a **concentrated** form into a **dispersed** form. This means that less energy is available to do work and the system becomes increasingly disordered. In an isolated system, **entropy** increases **spontaneously**.

How are the first and second laws of thermodynamics relevant to environmental systems?

Energy is needed in **ecosystems** to create order, such as to hold complex molecules together. Natural systems cannot be **isolated** because there must always be an **input** of energy for work to replace energy that is **dissipated**. Because of this energy loss, the maintenance of order in living systems needs a constant input of energy to replace the energy lost as heat through the inefficient transfer of energy.

One way energy enters an ecosystem is as sunlight energy. This sunlight energy is then changed into **biomass** by **photosynthesis**. That is, photosynthesis captures sunlight energy and transforms it into chemical energy. Chemical energy in producers may be passed along **food chains** as biomass, or given off as heat during respiration.

Subject vocabulary

system a collection of parts and the relationships between them, which together make a whole

thermodynamics physics that deals with the relationships and conversions between heat and other forms of energy

first law of thermodynamics law that states that energy cannot be created or destroyed: it can only be changed from one form into another; the first law of thermodynamics is known as the law of conservation of energy

second law of thermodynamics law that states that the transfer of energy through systems is inefficient as some of the energy is transformed into heat

transfer a process involving a change in location within the system but no change in state; an example of a transfer is water falling from clouds to the ground as rain

transformation a process that leads to the formation of new products – an example of a transformation is photosynthesis; it can also involve a change in state, such as water changing from water vapour to liquid water in clouds

entropy a measure of the amount of disorder in a system; the greater the disorder, the higher the level of entropy

ecosystem a community of organisms that depend on each other and the environment they live in

input the movement into something

biomass living matter, made from biological molecules

photosynthesis a process that captures sunlight energy and transforms it into the chemical bonds of glucose molecules. Carbon dioxide, water, and light are transformed into glucose and oxygen

food chain a simple diagram that shows feeding relationships in an ecosystem; energy flow from one organism to the next is shown by arrows

Available energy is used to do work such as growth, movement, and making **complex molecules**. The transformation and transfer of useable energy is not 100 per cent efficient; whenever energy is **converted** there is less usable energy at the end of the process than at the beginning. This means that there is a dissipation of energy which is then not available for work. The total amount of energy in a system does not change but the amount of available energy for work does change.

All energy eventually leaves the ecosystem as heat. No new energy has been created, it has simply been transformed and passed from one form to another. Heat is released because of the inefficient transfer of energy. This is true of all systems. Although **matter** can be recycled, energy cannot, and once it has been lost from a system in the form of heat energy, it cannot be made available again. Because the transfer and transformation of energy is inefficient, food chains tend to be short.

Model sentence: The following diagram summarizes the energy and matter transfers and transformations in environmental systems:

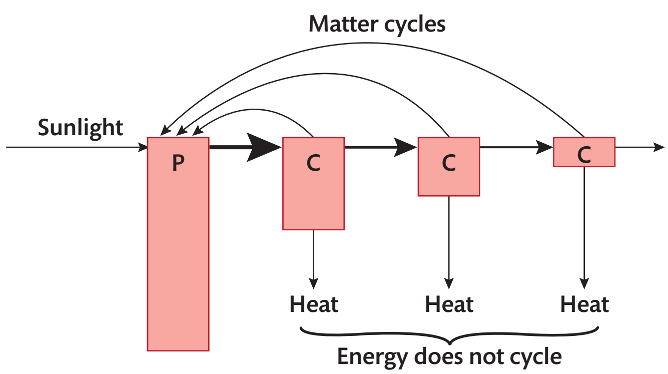

Figure 1.4 *Energy flow through a food chain; P = producers, C = consumers. The boxes show energy available to do work at each feeding level. Energy decreases through the food chain as some energy is converted to heat.*

Hints for success: You need to know the differences between the first and second laws of thermodynamics. The first law explains how energy entering a system must equal the energy remaining in the system plus the energy leaving the system. The second law of thermodynamics explains how energy transfers and transforms in living systems, which then leads to loss of energy from the system as heat. The order in living systems is only maintained by continuing input of new energy from the Sun.

Glossary

conserved kept and not lost

concentrated a lot of a substance in one place

dispersed when a substance is spread thinly and widely

spontaneously happening without an obvious external cause

isolated separated from others

dissipated lost/caused to disappear

complex molecule a molecule that contains many atoms, and is made from two or more molecular elements

converted changed into

Synonyms

constant......... kept the same

matter .... substance/ material

1.1.5 Explain the nature of equilibria

Subject vocabulary

equilibrium (plural – equilibria) a state (states) of balance among the components of a system

system a collection of parts and the relationships between them, which together make a whole

succession the orderly process of change over time in a community

steady-state equilibrium the condition of an open system in which there are no changes over the longer term, but in which there may be fluctuations in the very short term; there is overall stability in the system even though there are constant inputs and outputs of energy and matter

input the movement into something

output the movement out from something

static equilibrium equilibrium where there are no inputs or outputs of matter or energy, and no change in the system over time

Glossary

component one of several parts which together make up a whole system

fluctuation small increases and decreases

disturbance a change in the normal situation

integrity the state of being whole with all parts functioning normally

stability the state of not changing

deviation movement away from

example explanation of a particular problem

Synonyms

inanimate....... not living

Equilibrium can be defined as a state of balance among the **components** of a **system**.

This means that although there may be slight **fluctuations** in the system, these are within closely defined limits. Equilibrium allows systems to return to an original state after there has been **disturbance**. There may be long-term changes to the equilibrium of some systems while at the same time they retain **integrity**; for example, ecological **succession**.

Steady-state equilibrium

Most open systems in nature are in **steady-state equilibrium**. This means that even though there are constant **inputs** and **outputs** of energy and matter, there is overall **stability** within the system. Although there is overall stability there are usually changes, or fluctuations, in the system. These changes follow a fixed path and when there are **deviations** away from this path then there is always a return to equilibrium. The stability of this form of equilibrium means that the system can return to the steady-state after there has been disturbance. For **example**, when a tall tree that forms part of the roof of a tropical rainforest dies, the space it leaves behind is filled up again through the process of succession.

Static equilibrium

In **static equilibrium** there are no inputs or outputs of matter or energy and no change in the system over time. **Inanimate** objects such as a chair or table are in static equilibrium. No natural systems are in static equilibrium because all natural systems have inputs and outputs of energy and matter.

The following figures show the differences between steady-state and static equilibrium:

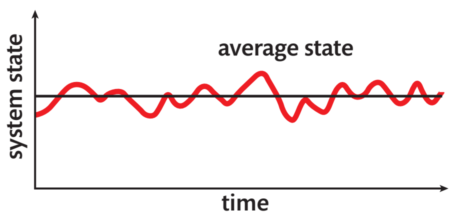

Figure 1.5a *Steady-state equilibrium*

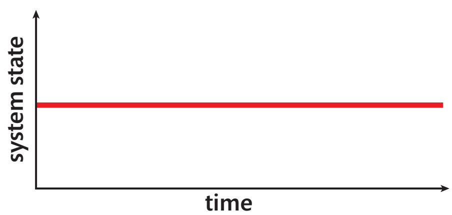

Figure 1.5b *Static equilibrium*

Model sentence: Some natural systems, such as ecosystems, may return to their original equilibrium, whereas other systems may not.

Systems can experience disturbance. **Stable equilibrium** is when a system returns to the original equilibrium after a disturbance. **Unstable equilibrium** is when a system does not return to the original equilibrium after disturbance, but forms a new equilibrium.

The following figures show the differences between stable and unstable equilibrium:

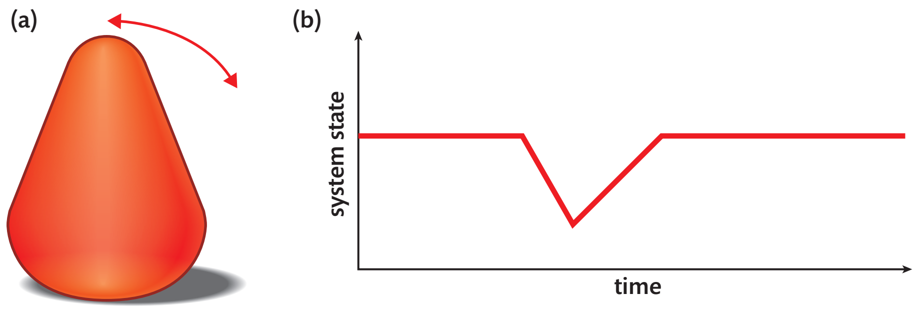

Figure 1.6a and b *Stable equilibrium. Disturbance to a system results in it returning to its original equilibrium.*

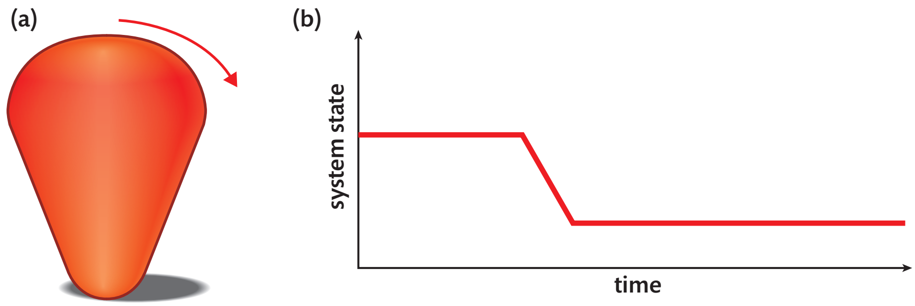

Figure 1.7a and b *Unstable equilibrium. Disturbance to a system results in it forming a new equilibrium very different from the first. Scientists believe that the Earth's climate may reach a new equilibrium following the effects of global warming and that conditions on Earth will be very different to what they are now.*

Subject vocabulary

stable equilibrium equilibrium where a system returns to the original equilibrium after a disturbance

unstable equilibrium equilibrium where a system does not return to the original equilibrium after disturbance but forms a new equilibrium

1.1.6 Define and explain the principles of *positive feedback* and *negative feedback*

Glossary

principles the rules of a scientific process

loop a process that repeats itself

mechanism process by which something takes place

time-lag gap in time between something being started and something taking effect

example explanation of a particular problem or issue

Subject vocabulary

feedback where the results of a process affect the input of the process

output the movement out from something

system a collection of parts and the relationships between them, which together make a whole

input the movement into something

equilibrium a state of balance among the components of a system

positive feedback feedback that leads to increasing change away from equilibrium and contributes to instability

negative feedback feedback that counteracts any change away from equilibrium and contributes to stability

What is feedback?

Feedback occurs when part of the **output** from a **system** returns as **input**, in order to influence later outputs.

The following figure shows a feedback **loop**:

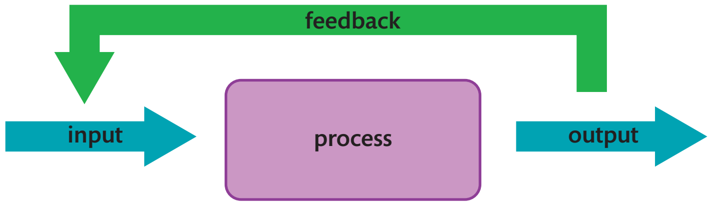

Figure 1.8 *Changes to the processes in a system lead to changes in the level of output. This feeds back to influence the level of input.*

Natural systems are able to control themselves by reaching **equilibrium** through feedback **mechanisms**.

Feedback involves **time-lags**, where it takes time for the feedback to have an effect.

Model sentence: There are two different types of feedback – positive feedback and negative feedback.

Positive feedback

Positive feedback can be defined as feedback that leads to increasing change away from equilibrium and contributes to instability.

An **example** of positive feedback is shown in the following figure:

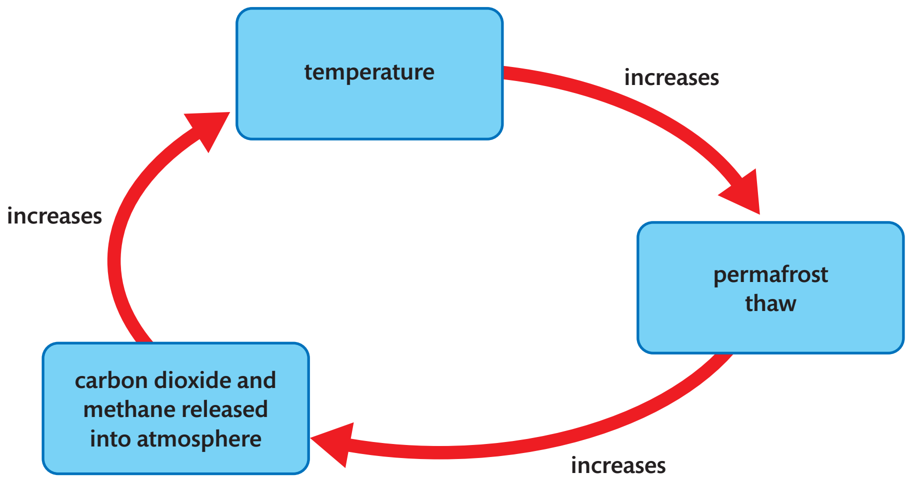

Figure 1.9 *How positive feedback can influence climate change.*

Negative feedback

Negative feedback can be defined as feedback that **counteracts** any change away from equilibrium. This form of feedback contributes to **stability**.

Negative feedback is a method of control that regulates itself. Through negative feedback, the system is able to maintain steady-state equilibrium.

See Figure 1.10 below for an example of negative feedback:

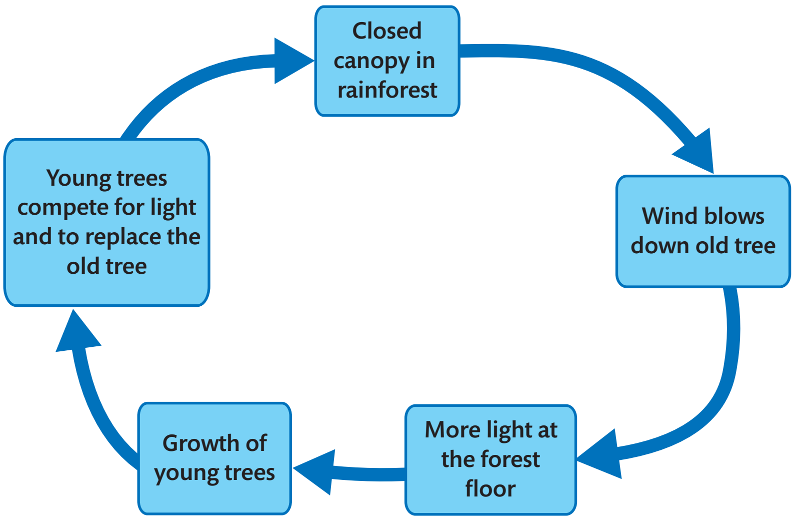

Figure 1.10 *How negative feedback can lead to steady-state equilibrium in a rainforest. Gaps in the forest canopy are closed when young trees compete for light and to replace the old tree.*

Hints for success: You need to know the differences between positive and negative feedback. Positive feedback speeds up deviation away from the equilibrium, for example the exponential growth of populations. Negative feedback counteracts deviation in a system and returns it to equilibrium, for example predator–prey relationships. Both positive and negative feedback involve time-lags.

Definitions of positive and negative feedback:

Positive feedback: feedback that leads to increasing change away from equilibrium and contributes to instability.

Negative feedback: feedback that counteracts any change away from equilibrium and contributes to stability.

Glossary

counteract work against

stability the state of not changing

1.1.7 Describe transfer and transformation processes

Subject vocabulary

input the movement into something

output the movement out from something

system a collection of parts and the relationships between them, which together make a whole

transfer a process involving a change in location within the system but no change in state

organic matter biological material in the process of decaying or decomposing

diffusion the movement of particles from a higher to a lower concentration

nutrients substances that provide nourishment essential for growth and the maintenance of life

consumption when one organism eats another organism

biomass living matter, made from biological molecules

transformation a process that leads to the formation of new products or involves a change in state

decomposition breakdown of organic matter by decomposers

photosynthesis a process that captures sunlight energy and transforms it into the chemical bonds of glucose molecules; carbon dioxide, water, and light are transformed into glucose and oxygen

respiration a chemical process occurring in all cells that transforms the energy in glucose molecules into ATP, releasing energy in the process; glucose is transformed in the presence of oxygen into carbon dioxide and water

Glossary

state form that matter takes: solid, liquid, or gas

Inputs and **outputs** from **systems** can be either transfer or transformation processes.

What are transfer processes?

A **transfer** is a process where there is a change in location within the system, but there is no change in **state**. An example of a transfer is water falling from clouds to the ground as rain. Dead **organic matter** entering a lake is another example of a transfer process.

In Figure 1.1 (page 2) transfer processes would include:

- **Diffusion**: allows the movement of **nutrients** and water into the tree.
- **Consumption**: transfers **biomass** from one level of a food chain to another.

What are transformation processes?

A **transformation** is a process that leads to the formation of new products. It can also involve a change in state. An example of a transformation is water in clouds changing from water vapour to liquid water. The **decomposition** of dead organic matter is another example of a transformation process.

In Figure 1.1 (page 2) transformation processes would include:

- **Photosynthesis**: converts sunlight energy, carbon dioxide and water into glucose and oxygen.
- **Respiration**: changes biomass into carbon dioxide and water, and releasing some heat.

Transfers are processes that lead to a change in location but not a change in state;

Transformations are processes that lead to the formation of new products or a change in state.

1.1.8 Distinguish between flows and storages in relation to systems

System diagrams contain storages and flows.

Model sentence: Flows are movement from one place to another in the system and are shown by arrows.

Flows are either inputs or outputs. Inputs are movements into a storage and outputs are movements out of a storage.

Model sentence: Storages are where something is kept in a system and are shown by boxes.

The following diagram shows flows and storages in a social system:

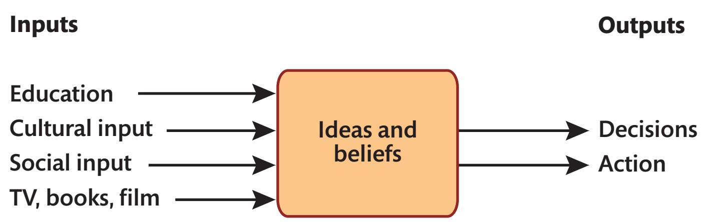

Figure 1.11 *A social system, showing flows and storage. Flows are inputs and outputs, and storage is the ideas and beliefs of the society.*

Flows are movements from one place to another in a system;

Storages are when something is kept in a system.

Subject vocabulary

system a collection of parts and the relationships between them, which together make a whole

storage where something is kept

flow movement from one place to another

input the movement into something

output the movement out from something

social system the people in a society viewed as a system and organized by a characteristic pattern of relationships

1.1.9 Construct and analyse quantitative models involving flows and storages in a system

Subject vocabulary

model a simplified description designed to show the structure and workings of a system

system a collection of parts and the relationships between them, which together make a whole

flow movement from one place to another

storage where something is kept

ecosystem a community of organisms that depend on each other and the environment they live in

Synonyms

structure .... organization/ arrangement

workings .... how something is organized

linkage........... connection

complexity...... containing many parts which are difficult to understand

Glossary

excrete get rid of waste, produced by chemical reactions in cells, from the body

understory plants plants that grow underneath the leaf cover of other plants. For example, shrubs growing under a tree are understory plants

root the part of a plant which grows under the ground

leach into pass into

quantitative relating to the amount of something

relative compared to one another

in proportion (to) the correct relationship according to size, shape, or position

tissue decay the breakdown of biomass to form litter

mineralization the conversion of organic molecules into inorganic molecules by soil organisms

humification the process of the formation of humus from plant and animal remains

A **model** is a simplified description designed to show the **structure** and **workings** of a **system**. Models can be used to show the **flows**, **storages**, and **linkages** within **ecosystems**. While they are unable to show much of the **complexity** of the real system, they still help us to understand ecosystem function better. The following figure shows a model for an ecosystem:

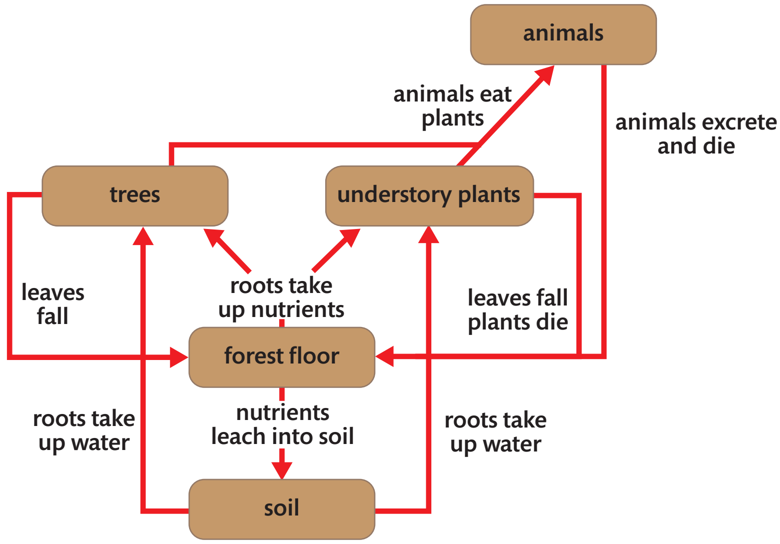

Figure 1.12 *Models are simplified versions of reality. They can show much about the main processes in the ecosystem and show key linkages. This is a model of an ecosystem.*

Model sentence: Quantitative models show the relative sizes of flows and storages.

The width of arrows can vary in size; wider arrows are used to show larger flows. This means that the size of flows can be drawn **in proportion to** other flows. The size of boxes can also vary; larger boxes are used to show larger storages. Quantitative models can be used to analyse and compare different models.

Model sentence: The following models compare and contrast two different systems:

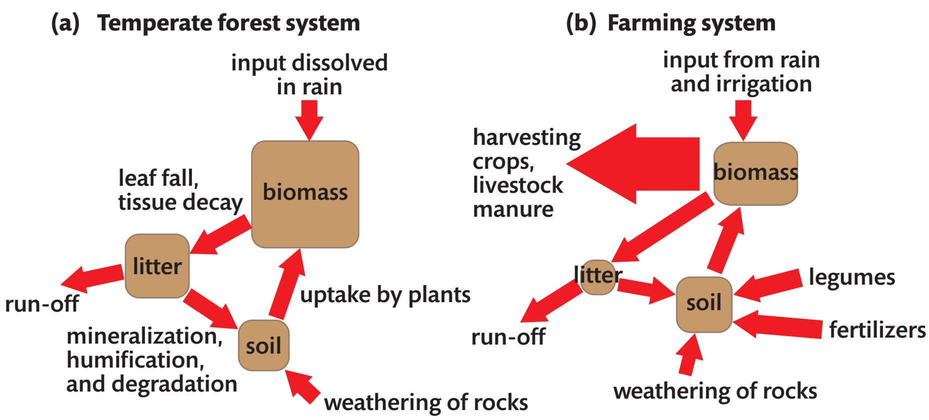

Figure 1.13 *Quantitative models showing nutrient cycles for two different systems. In each case the width of the arrow indicates the relative size of the flow. Similarly the size of the box indicates the relative size of the storage.*

Model sentence: The quantitative models shown in the figure can be analysed by comparing the relative size of flows and storages.

The models in Figure 1.13 show quantitative information about the different systems as the **nutrient** flows and storages have been drawn in proportion to one another. The **biomass** storage is larger in the woodland. The **litter** storage is larger in the forest. There is a large output flow in the farming system because of the **harvested crops** and **livestock**. The diagrams also show that **legumes** and **fertilizers** are additional inputs in the farming system. Other flows are the same in both systems, such as the input from **dissolved** rain. Models that include quantitative descriptions of the system provide more meaningful information.

Hints for success: When you draw a systems diagram make sure you write the processes on the input and output arrows. By labelling inputs and outputs in this way you can show which transfers and transformations are taking place.

Glossary

degradation wearing down and disintegrating

weather/weathering change through the long-term action of sun, rain, and wind

Subject vocabulary

nutrients substances that provide nourishment essential for growth and the maintenance of life

biomass living matter, made from biological molecules

Glossary

litter dead leaves and plants

harvest collect crops from the field

crop plants such as wheat or rice which are grown by farmers and used as food

livestock farm animals

legume pea or bean plant

fertilizer organic matter or chemicals used to increase the fertility of a soil

dissolve mix and form part of a liquid

1.1.10 Evaluate the strengths and limitations of models

Subject vocabulary

model a simplified description which aims to show the structure or workings of a system

system a collection of parts and the relationships between them, which together make a whole

Glossary

simplify/simplification make something easier or less complicated to understand

aquarium a glass container for fish and other water animals and plants

concept an idea of how something is

oversimplify/oversimplification describe something in a way that is too simple

Synonyms

structure .... organization/arrangement

workings .... show how something is organised

complex......... complicated/difficult to understand

limitation .... weakness/disadvantage

What is a model?

A **model** can be defined as a **simplified** description, which aims to show the **structure** or **workings** of a **system**.

Some models are **complex**, such as models that predict the effect of climate change. Other models are simple, such as a model of an **aquarium** ecosystem. Even simple ecosystems like the aquarium ecosystem can show many ecological **concepts**.

Evaluation of models

Strengths of models

- Models allow scientists to predict and simplify complex systems.
- They allow inputs to be changed and outcomes examined without having to wait a long time, as we would have to if studying real events.
- Models allow results to be shown to other scientists and to the public, and are easier to understand than detailed information about the whole system.

Limitations of models

- Different models may show different effects using the same data. For example, models that predict the effect of climate change may give very different results.
- Systems may be very complex and when models of them are **oversimplified** they may become less accurate. For example, there are many complex factors involved in atmospheric systems.
- Because many assumptions have to be made about these complex factors, climate models may not be accurate.
- The complexity and oversimplification of climate models has led some people to criticise the **limitations** of these models.
- Any model is only as good as the data that are used in them. In addition, the data put into the model may not be reliable.
- Models rely on the expertise of the people making them and this can lead to inaccuracies.
- Different people may interpret models in different ways and so come to different conclusions. People who would gain from the results of the models may use them to their advantage.

Hints for success: You need to be able to evaluate the use of models. The advantage of models is that they clearly show links between parts of a system and give a clear summary of complex interrelationships. The disadvantage of models is that they require scientists to simplify complex systems and include assumptions. These simplifications and assumptions can lead to loss of information and inaccuracies.