Environmental Systems and Societies

for the IB DIPLOMA

Andrew Davis
and Garrett Nagle

HODDER
EDUCATION

Environmental Systems and Societies

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Contents

How to use this revision guide

Welcome to the *Environmental Systems and Societies (ESS) for the IB Diploma Revision Guide*. This book will help you plan your revision and work through it in a methodological way. It follows the ESS syllabus topic by topic, with revision and practice questions at the end of each section to help you check your understanding.

Features to help you succeed

You can keep track of your revision by ticking off each topic heading in the book. There is also a checklist at the end of the book. Use this checklist to record progress as you revise. Tick each box when you have:

- revised and understood a topic
- tested yourself using the **Quick check questions**
- used the **Exam practice questions** and gone online to check your answers.

Use this book as the cornerstone of your revision. Don't hesitate to write in it and personalise your notes. Use a highlighter to identify areas that need further work. You may find it helpful to add your own notes as you work through each topic. Good luck!

Expert tips
These tips give advice that will help you boost your final grade.

Common mistakes
These identify typical mistakes that students make and explain how you can avoid them.

Key word definitions
Definitions are provided on the pages where the essential key terms appear. These key words are those that you can be expected to define in exams. A **glossary** of other essential terms, highlighted throughout the text, is given at the end of the book.

CASE STUDIES
Parts of the syllabus require you to use case studies. Examples are given in the relevant sections of the book.

Worked examples
Some parts of the course require you to carry out mathematical calculations, plot graphs, and so on. These examples show you how.

■ QUICK CHECK QUESTIONS
Use these questions to make sure that you have understood a topic. They are short, knowledge-based questions that use information directly from the text.

EXAM PRACTICE
Practice exam questions are provided at the end of each section. Use them to support your revision and practise your exam skills.

Getting to know Paper 1 and Paper 2

At the end of your ESS course you will sit two papers – Paper 1 and Paper 2. Paper 1 is worth 30% of the final marks and Paper 2, 50% of the final marks. The other assessed part of the course (20%) is made up of the Internal Assessment (practical work), which is marked by your teacher.

There are no options in ESS and therefore all topics need to be thoroughly revised for both papers. Here is some general advice for the exams:

- Make sure you have learned the command terms (e.g. evaluate, explain, outline).There is a tendency to focus on the content in a question rather

than the command term, but if you do not address what the command term is asking of you then you will not be awarded marks. (Command terms are covered on pages ix–xiii.)
- Answer all questions and do not leave gaps.
- Do not write outside the answer boxes provided – if you do so this work will not be marked.
- If you run out of room on the page, use continuation sheets and indicate clearly that you have done this on the cover sheet. (The fact that the question continues on another sheet of paper needs to be clearly indicated in the text box provided.)
- Plan your time carefully before the exams – this is especially important for Paper 2 (see below).

Paper 1

Paper 1 (1 hour) contains short-answer and data-based questions. The total number of marks for this paper is 45, with questions covering the whole breadth of the syllabus.
- There are usually several marks for definitions, so make sure you have learned the key word definitions in this book.
- As the paper is only out of 45 marks, the questions cannot cover all aspects of the syllabus. It is therefore essential that you thoroughly revise the whole syllabus so that you can tackle any questions that come up.
- The size of the boxes provided gives an indication of the length of answer expected – make sure your answers are concise.
- Look carefully at the number of marks awarded for each question – for example, if 2 marks are awarded the examiner is looking for two different points.

Paper 2

Paper 2 (2 hours) is in two sections: Section A is based on a resource booklet and is worth a total of 25 marks; in Section B you must answer two essay questions from a choice of four. Twenty marks are available per essay, making a total of 40 marks for the essay section. Total marks for the paper are therefore 65.

In the resource booklet you will be given a range of data in various forms (e.g. maps, photos, diagrams, graphs and tables) relating to a specific case study. Questions will test your knowledge of the syllabus and your ability to apply this to the new case study. You are required to answer a series of questions, which can involve a variety of command terms, by analysing these data.
- Do not spend too much time on one of the two sections.
- Plan your time carefully (do this *before* the exam).
- By practising past papers you will be able to work out how much time you need to take. This will vary from student to student, but here is some general advice:
  - You should be looking to spend less time on Section A (the resource booklet questions) than on Section B (the two essays).
  - Aim to spend about 45 minutes on Section A.
  - The essays need to be thought about carefully and planned – aim to spend a *minimum* of 35 minutes per essay but to move on if you are still on the first one after 40 minutes.
  - If English is not your first language then you may need to spend more time on the resource booklet.
- Choose your essays carefully. Look at all sections of an essay before making your choices.
- Some students write pages on sections worth only a few marks, and then run out of time later on. Look carefully at the number of marks available for each question and adjust the amount of time you spend on that question accordingly. Writing a plan for your essays will help you.

- There are usually several sections in an essay question – make sure you answer all parts.
- Case studies will help you answer Paper 2 essay questions – make sure you have learned these from the course (examples are given in this book). You should use your own case studies to answer the essay questions rather than taking ideas from the resource booklet case study.
- Essays should be subdivided into sections, not written as one long paragraph – examiners like this as it makes the paper easier to read and mark.
- Leave at least one line between sections of an essay for clarity, and note on your scripts if a continuation sheet has been used.

Assessment objectives

To successfully complete the course, you need to have achieved the following objectives:

1 Demonstrate an understanding of information, terminology, concepts, methodologies and skills with regard to environmental issues.

2 Apply and use information, terminology, concepts, methodologies and skills with regard to environmental issues.

3 Synthesise, analyse and evaluate research questions, hypotheses, methods and scientific explanations with regard to environmental issues.

4 Using a holistic approach, make reasoned and balanced judgements using appropriate economic, historical, cultural, socio-political and scientific sources.

5 Articulate and justify a personal viewpoint on environmental issues with reasoned argument, while appreciating alternative viewpoints, including the perceptions of different cultures.

6 Demonstrate the personal skills of cooperation and responsibility appropriate for effective investigation and problem solving.

7 Select and demonstrate the appropriate practical and research skills necessary to carry out investigations with due regard to precision.

These assessment objectives are examined in the following way:

Assessment objectives	Which component addresses this assessment objective?	How is the assessment objective addressed?
1–3	Paper 1	Short-answer and data-based questions
1–5	Paper 2	Section A: case study
		Section B: two structured essays (from a choice of four)
1–7	Internal Assessment: practical work	–

Command terms

Command terms indicate the depth of treatment required for a given assessment statement. Objectives 1 and 2 address simpler skills; objectives 3, 4 and 5 relate to higher-order skills.

It is essential that you are familiar with these terms, for Papers 1 and 2, so that you are able to recognise the type and depth of response you are expected to provide.

The tables on the following pages show examples of all of the command terms, with questions taken from the current syllabus. Where no date is given, the command term has not been used so far in the new ESS syllabus.

Objective 1

Demonstrate an understanding of information, terminology, concepts, methodologies and skills with regard to environmental issues.

Term	Definition	Sample question	Advice for success
Define	Give the precise meaning of a word, phrase, concept or physical quantity.	Japanese knotweed can be described as a pioneer species. Define the term *pioneer species*. [1] (Paper 1, Nov 2012)	The glossary in the course guide is a good starting point for learning definitions.
Draw	Represent by means of a labelled, accurate diagram or graph, using a pencil.	For an ecosystem you have studied, draw a food chain of at least four named species. [1] (Paper 1, May 2011)	Be prepared to draw diagrams in both Papers 1 and 2. Your answer will be electronically scanned, so draw the diagram or graph clearly and create labels that can be easily read. A ruler (straight edge) should be used for straight lines. Diagrams should be drawn to scale. Graphs should have points correctly plotted (if appropriate) and joined by a straight line or smooth curve.
Label	Add labels to a diagram.	Label a point on Figure 5 to show the likely location of the power station responsible for the thermal pollution of local waters. [1] (Paper 1, Nov 2012)	You need to be precise – in this case, the power station must be on the land!
List	Give a sequence of brief answers with no explanation.	List three types of solid domestic waste. [1] (Paper 1, May 2010)	A list is likely to consist of just a few words – you will not gain any credit for an explanation or a detailed description.
Measure	Obtain a value for a quantity.	Measure the decrease in the thickness of the ice sheet on the south coast of Greenland between 1950 and 2010.	Use the scale to measure the extent of the decline.
State	Give a specific name, value or other brief answer without explanation or calculation.	State the term for the pattern of vegetation shown in Figure 1. [1] (Paper 1, Nov 2012)	The answer is likely to be short as well as specific.

Objective 2

Apply and use information, terminology, concepts, methodologies and skills with regard to environmental issues.

Term	Definition	Sample question	Advice for success
Annotate	Add brief notes to a diagram or graph.	The diagram below shows two biotic components of the carbon cycle: a plant and a bird. Annotate the diagram to show the inputs and outputs of carbon through photosynthesis and respiration. [2] (Paper 1, Nov 2010)	The notes should aid in the description or explanation of the diagram or graph.
Apply	Use an idea, equation, principle, theory or law in relation to a given problem or issue.	Apply Simpson's Diversity Index to work out the diversity of species in the woodland ecosystem.	The formula for Simpson's Diversity Index will be supplied and does not need to be memorised.
Calculate	Obtain a numerical answer, showing the relevant stages of working.	Calculate the percentage increase in grain production between 1967 and 2005. [1] (Paper 1, Nov 2012)	You should include all the steps involved in calculating the answer. The final response should be made clear and have appropriate units where applicable.
Describe	Give a detailed account.	Describe one other system where human activities have created environmental problems through a positive feedback system and explain how the system can be brought back to balance. [8] (Paper 2, Nov 2012)	Be guided by the number of marks assigned to the question. More marks require a more detailed description.
Distinguish	Make clear the differences between two or more concepts or items.	Distinguish between *negative feedback* and *positive feedback*. [2] (Paper 1, May 2010)	In this type of question it is essential that you emphasise the differences between the two concepts – it is not acceptable to just define the two terms/give two separate descriptions.
Estimate	Obtain an approximate value.	Estimate the area covered by national parks in Borneo.	Use the scale on the map and your ruler to work out an approximate value. You do not need to spend a lot of time measuring round curves.
Identify	Provide an answer from a number of possibilities.	Identify two limiting factors affecting the vegetation in the alpine meadows. [2] (Paper 1, Nov 2012)	Only a very brief answer is needed here.
Outline	Give a brief account or summary.	Outline two problems caused by the use of herbicides to control invasive species such as Japanese knotweed. [2] (Paper 1, Nov 2012)	Two negative impacts of the use of herbicides must be described briefly.

Objectives 3, 4 and 5

Synthesise, analyse and evaluate research questions, hypotheses, methods and scientific explanations with regard to environmental issues.

Using a holistic approach, make reasoned and balanced judgements using appropriate economic, historical, cultural, socio-political and scientific sources.

Articulate and justify a personal viewpoint on environmental issues with reasoned argument while appreciating alternative viewpoints, including the perceptions of different cultures.

Term	Definition	Sample question	Advice for success
Analyse	Break down in order to bring out the essential elements or structure.	Analyse the population structure shown in the population pyramid.	From within the population pyramid determine the basic age and gender demographics of the population and highlight them within your response.
Comment	Give a judgement based on a given statement or result of a calculation.	Comment on the relationship between population growth and food supply.	You should reach a conclusion on whether you think population growth is out-stripping food resources.
Compare and contrast	Give an account of similarities and differences between two (or more) items or situations, referring to both (or all) of them throughout.	Compare and contrast the abiotic factors found in the straight part of the river with the abiotic factors found in the meandering part of the river. [3] (Paper 2, Nov 2012)	You should describe and explain the similarities (compare), as well as describe and explain the differences (contrast) between the abiotic factors in the two named parts of the river.
Construct	Display information in a diagrammatic or logical form.	Construct a simple diagram to show three inputs that can lead to increases in two outputs in a food production system. [3] (Paper 1, Nov 2012)	This may involve boxes and arrows, for example in the form of a flow diagram. It is very important that your construction is clear.
Deduce	Reach a conclusion from the information given.	Deduce, giving a reason, whether the figure below could represent the transfer of energy in a terrestrial ecosystem. [1] (Paper 1, May 2012)	Your answer must state the conclusion reached.
Derive	Manipulate a mathematical relationship to give a new equation or relationship.	Using the crude birth rate and crude death rate, derive the natural increase for the selected populations.	Crude birth and death rates are given in rates per thousand whereas natural increase is given in rates per hundred (per cent) so a conversion/manipulation of the data must be conducted to derive the answer. Check the units that are used.
Design	Produce a plan, simulation or model.	Design a conservation area for the protection of a named species.	Design a reserve, using appropriate criteria such as: size, shape, edge effects, corridors and proximity to other reserves.
Determine	Obtain the only possible answer.	Determine the stage of demographic transition represented by each age/sex pyramid. [2] (Paper 1, Nov 2012)	You should determine a definite stage, with no alternatives.

Term	Definition	Sample question	Advice for success
Discuss	Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.	With reference to all of the data, discuss the relationship between natural income and the sustainability of human activities in the Danube River delta. [4] (Paper 2, Nov 2012)	The response should contain evidenced commentary on the relationship between natural income and the sustainability of human activities in the Danube River delta. You must make sure that you consider both/all sides of the issues.
Evaluate	Make an appraisal by weighing up the strengths and limitations.	Evaluate the policies or legislation or actions that exist locally, nationally and internationally that address this issue. [7] (Paper 2, Nov 2012)	You must name the policies, legislation or actions being discussed. All three levels need to be evaluated. The response should contain mention of both the advantages and disadvantages of the policies and arrive at a conclusion.
Explain	Give a detailed account, including reasons or causes.	Explain why rates of net primary productivity are higher in some parts of the planet than others. [2] (Paper 1, Nov 2012)	Assume that you will need to briefly describe before you explain, unless that was required in the preceding part of the question.
Justify	Give valid reasons or evidence to support an answer or conclusion.	Justify your personal viewpoint on the value of international cooperation in the conservation of tropical rainforests. [2] (Paper 2, May 2010)	In determining the approximate number of pieces of evidence required in your response look to the marks assigned to the question. Be specific. Here you need to consider the role of international cooperation, not just conservation of rainforests.
Predict	Give an expected result.	Predict the effect on nutrient cycling of increased precipitation over many years in a region that is currently a steppe. [3] (Paper 1, Nov 2011)	There are 3 marks available so you should refers to storages in the biomass, litter and soil, as well as the flows between them and the inputs and outputs to and from the system. When you are asked to make a prediction you will be provided with information to assist you – be sure to use it.
Solve	Obtain the answer(s) using algebraic and/or numerical methods and/or graphical methods.	Using the data provided, solve the net primary productivity per kg biomass per year.	For a response that requires a solution, include an answer with units where appropriate and show all the steps involved in coming to an answer.
Suggest	Propose a solution, hypothesis or other possible answer.	Suggest one way in which the pattern of vegetation shown in Figure 1 might change as a result of global warming. [1] (Paper 1, Nov 2012)	The term 'suggest' is used when there are several possible answers and you may have to give reasons or a judgement.

Countdown to the exams

4–8 WEEKS TO GO

- Start by looking at the syllabus and make sure you know exactly what you need to revise.
- Look carefully at the checklist in this book and use it to help organise your class notes and to make sure you have covered everything.
- Work out a realistic revision plan that breaks down the material you need to revise into manageable pieces. Each session should be around 25–40 minutes with breaks in between. The plan should include time for relaxation.
- Read through the relevant sections of this book and refer to the expert tips, common mistakes, key definitions, case studies and worked examples.
- Tick off the topics that you feel confident about, and highlight the ones that need further work.
- Look at past papers. They are one of the best ways to check knowledge and practise exam skills. They will also help you identify areas that need further work.
- Try different revision methods, for example summary notes, mind maps and flash cards.
- Test your understanding of each topic by working through the **Quick check** and **Exam practice questions** at the end of each section.
- Make notes of any problem areas as you revise, and ask a teacher to go over them in class.

1 WEEK TO GO

- Aim to fit in at least one more timed practice of entire past papers, comparing your work closely with the mark scheme.
- Examine the checklist carefully to make sure you haven't missed any of the topics.
- Tackle any final problems by getting help from your teacher or talking them over with a friend.

THE DAY BEFORE THE EXAMINATION

- Look through this book one final time. Look carefully through the information about Paper 1 and Paper 2 to remind yourself what to expect in both papers.
- Check the time and place of the exams.
- Make sure you have all the equipment you need (e.g. extra pens, a watch, tissues). Make sure you have a calculator – this is needed in both papers.
- Allow some time to relax and have an early night so you are refreshed and ready for the exams.

MY EXAMS

ESS PAPER 1
Date:...................................
Time:...................................
Location:...............................

ESS PAPER 2
Date:...................................
Time:...................................
Location:...............................

Topic 1 Systems and models

Systems

Concept and characteristics of systems

- A system can be divided into parts, or components, which can each be studied separately: this is called a 'reductionist' approach.
- A system can also be studied as a whole, and patterns and processes described for the whole system: this is called a 'holistic' approach.
- The course focuses on ecosystems, but the systems approach can equally be applied to economic, social and value systems.
- The systems approach is shown in Figure 1.1.

> **Key word definition**
> A **system** is an assemblage of parts and the relationships between them, which together constitute an entity or whole.

Figure 1.1 The systems approach allows different disciplines to be studied in the same way, and for links to be made between them

Systems can be shown as diagrams where they can be divided into storages and flows (Figure 1.2).

Figure 1.2 A simple systems diagram showing storage and flows

> **Expert tip**
> Draw bold, clear, well-labelled diagrams.

- **Storages** are represented by boxes.
- **Flows** are represented by arrows.
- Arrows represent **inputs** and **outputs** from the system.

An example is shown in Figure 1.3.
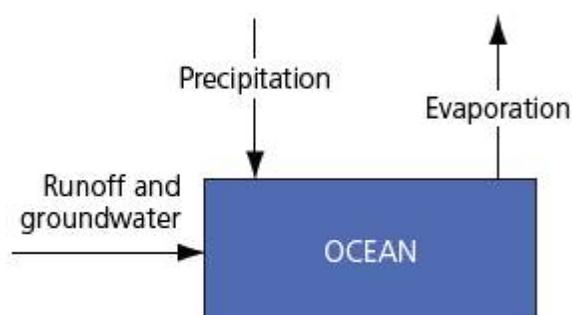
Figure 1.3 A diagram of an ocean system, with flows into and out from the storage (the ocean)

> **Common mistake**
> If you are asked to construct a *diagram* of a system, do not draw a picture. This reduces the time available for completing the question. You are expected to draw diagrams with boxes and arrows, representing storages and flows.

Transfer and transformation processes

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

- **Transfers** are processes that involve a change in location within the system but no change in state, for example water flowing from groundwater into a river.
- **Transformations** lead to the formation of new products (e.g. photosynthesis, which converts sunlight energy, carbon dioxide and water into glucose and oxygen) *or* involve a change in state (e.g. water evaporating from a leaf into the atmosphere).

Storages and flows can be drawn in proportion (i.e. to scale). This **quantitative** way of showing information about the system gives extra information and adds value to models (Figure 1.4).

Common mistake

Do not confuse **transfers** with **transformations**. Transfers only involve a change in location, whereas transformations involve a change in state or new products.
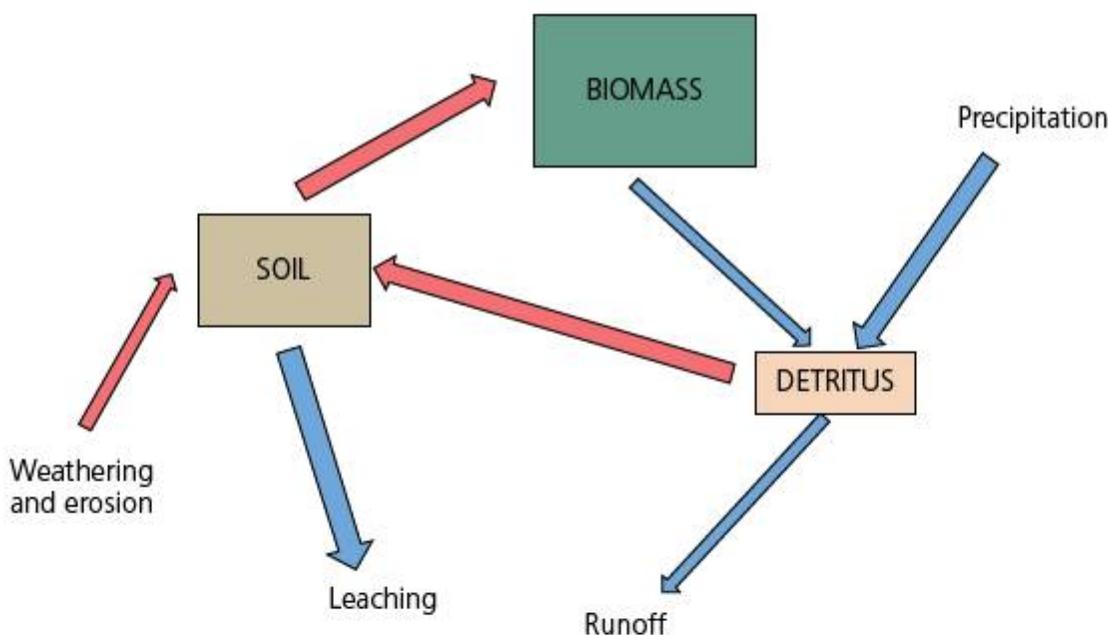
Figure 1.4 Diagram showing a nutrient model for a rainforest ecosystem. The size of the boxes represents the amount of nutrients stored, and the width of the arrows the size of the nutrient flows

Expert tip

When drawing a diagram, include processes on the input and output arrows to show the transfers (blue arrows in Figure 1.4) and transformations (red arrows in Figure 1.4) taking place.

If a question gives data on the size of the flows or storages, you are expected to show these on diagrams either by drawing boxes and arrows proportionally, or by including numbers.

The systems concept on a range of scales

Systems can range in size from small (e.g. a cell) to large (e.g. a rainforest). The Earth itself can be seen as a global ecosystem.

Daisyworld

The **Daisyworld** model was developed by James Lovelock to show how the **Gaia hypothesis** could regulate life on Earth. Daisyworld (Figure 1.5) is a simple model for a worldwide ecosystem:

- The only life on Daisyworld is black or white daisies. The rest of the planet is bare earth.
- The temperature of the planet is determined by the amount of sunlight absorbed by the surface of the planet.
- The Sun's heat output is gradually increasing.
- Black daisies absorb more solar energy and warm the planet – they will be abundant in the early history of Daisyworld when the Sun is cooler.
- White daisies reflect more of the Sun's energy – these will become more abundant as the Sun's heat energy increases.
- The temperature of the planet remains the same, within narrow limits.
- The temperature of the planet is therefore self-regulating.

Key word definition

The **Gaia hypothesis** compares the Earth to a living organism in which feedback mechanisms maintain equilibrium. It describes how the living and non-living components of the global biosphere regulate the conditions for life on Earth. It was developed by James Lovelock and named after an ancient Greek Earth goddess.

(a)   (b)
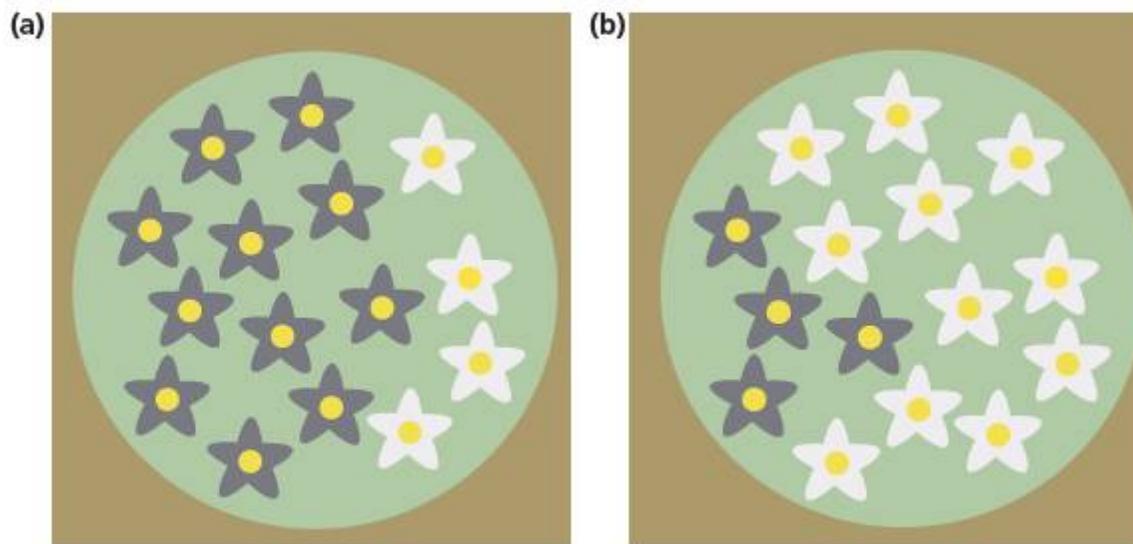
Figure 1.5 The Daisyworld model. a) Daisyworld early in its history;
b) Daisyworld late in its history, after its Sun has become brighter

Open systems, closed systems and isolated systems

Revised ☐

There are three different types of system – **open**, **closed** and **isolated**. Differences depend on how matter and energy move into and out of the system.

Figure 1.6 The Earth – an example of a closed system

■ **QUICK CHECK QUESTIONS**
3   Outline the differences between open, closed and isolated systems. Give examples of each.

Key word definitions
Open systems exchange both matter and energy with their surroundings (e.g. an ecosystem).

Closed systems exchange only energy but not matter with their surroundings (e.g. the Earth – Figure 1.6).

Isolated systems these do not exchange either matter or energy with their surroundings (e.g. the Universe).

Expert tip
Systems can be described as closed or open (but, aside from the Universe, not isolated) depending on the scale at which they are examined. Marks will be awarded for showing an appropriate understanding of the roles of inputs and outputs, matter and energy.

The first and second laws of thermodynamics and their relevance to environmental systems

Revised ☐

The first law of thermodynamics (law of conservation of energy) states that energy entering a system equals energy leaving it, i.e. energy can neither be created nor destroyed.

The second law of thermodynamics states that energy in systems is gradually transformed into heat energy due to inefficient transfer, thereby increasing disorder (**entropy**).

■ Energy flows through ecosystems. Energy enters as sunlight energy and is converted to new biomass and heat.
■ The energy entering the system equals the energy leaving it (first law).
■ Energy is inefficiently moved through food chains in the process of respiration and production of heat energy (second law).
■ Initial absorption and transfer of energy by producers is also inefficient due to reflection, transmission, light of the wrong wavelength and inefficient transfer of energy in photosynthesis (second law).

Key word definition
Entropy is a measure of the amount of disorder, chaos or randomness in a system; the greater the disorder, the higher the level of entropy.

- Light energy starts the food chain but is then transferred from producer to consumers as chemical energy.
- As a result of the inefficient transfer of energy, food chains tend to be short.

The nature of equilibria

In ecosystems, such as temperate forests, inputs and outputs of energy and matter change over time. This leads to changes in the population dynamics of communities, with populations increasing and decreasing in abundance. Overall the forest remains the same (**steady-state equilibrium**). Systems have a tendency to return to the original equilibrium, rather than adopting a new one, following disturbance.

Systems can have **stable** or **unstable** equilibrium (see Figures 1.7, 1.8, 1.9 and 1.10).

> **Key word definitions**
> **Equilibrium** is a state of balance among the components of a system.
>
> **Steady-state equilibrium** is the condition of an open system in which there are no changes over the longer term, but in which there may be oscillations in the very short term.
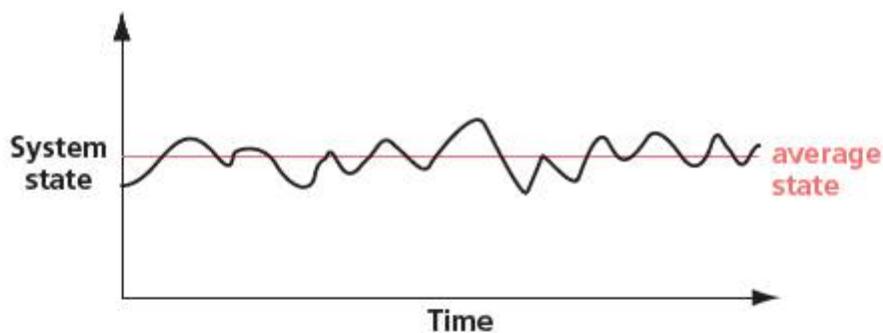
Figure 1.7 Steady-state equilibrium. There are continuing inputs and outputs of matter and energy, but the system as a whole remains in a more-or-less constant state (for example, a climax ecosystem)

> **Key word definition**
> **Stable equilibrium** is the tendency in a system for it to return to a previous equilibrium condition following disturbance. This is in contrast to **unstable equilibrium**, which forms a new equilibrium following disturbance.
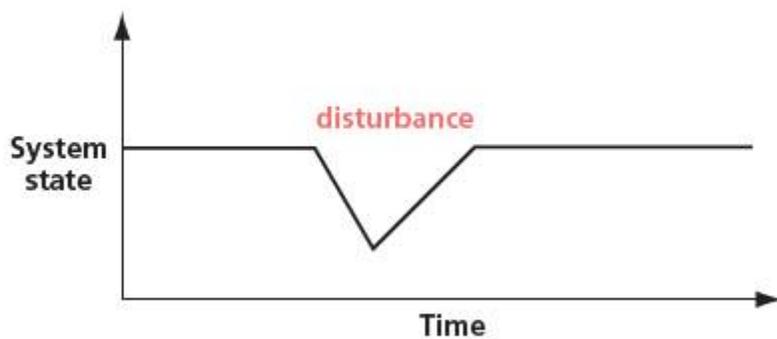
Figure 1.8 Stable equilibrium. Disturbance leads to a return to the original equilibrium
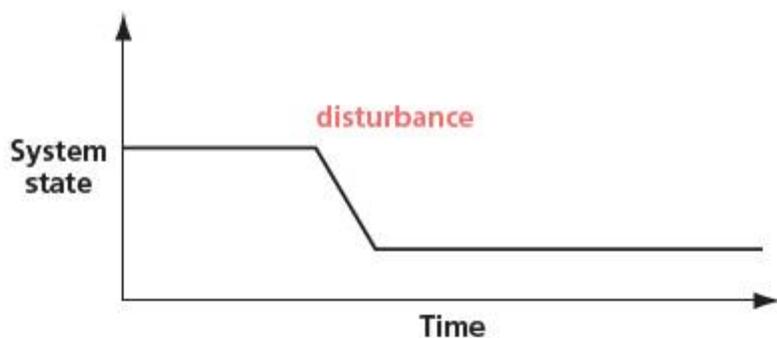
Figure 1.9 Unstable equilibrium. The system moves to a new equilibrium following disturbance
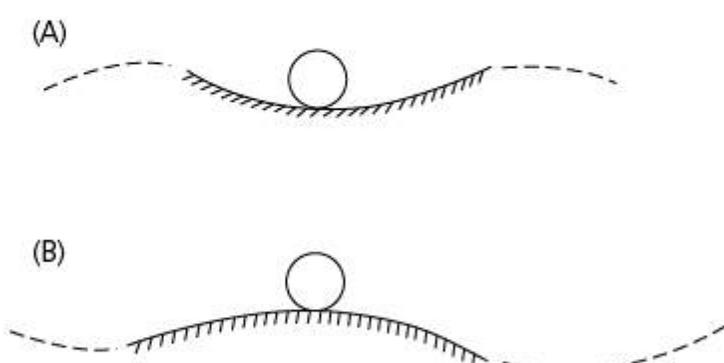
Figure 1.10 Diagrams showing the difference between (A) stable and (B) unstable equilibrium

■ **QUICK CHECK QUESTIONS**
4 Define *steady-state equilibrium*.
5 Explain the differences between stable and unstable equilibrium.

Positive feedback and negative feedback

Figures 1.11 and 1.12 show examples of positive and negative feedback.
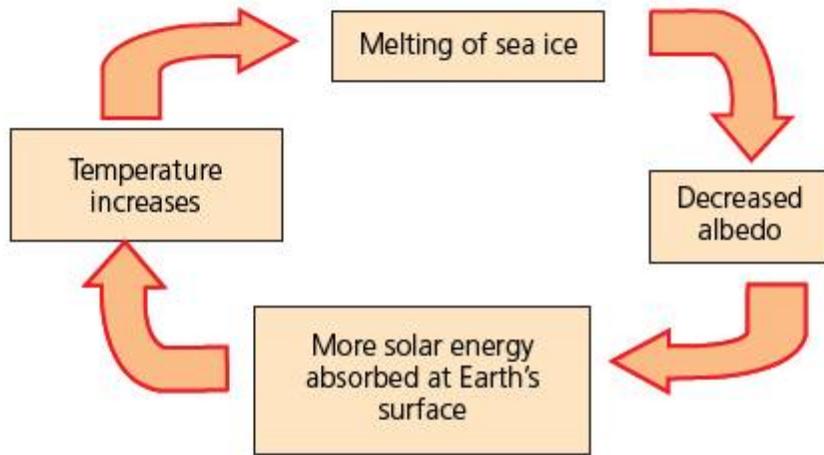
Figure 1.11 An example of positive feedback: the effect of rising temperatures on planetary albedo
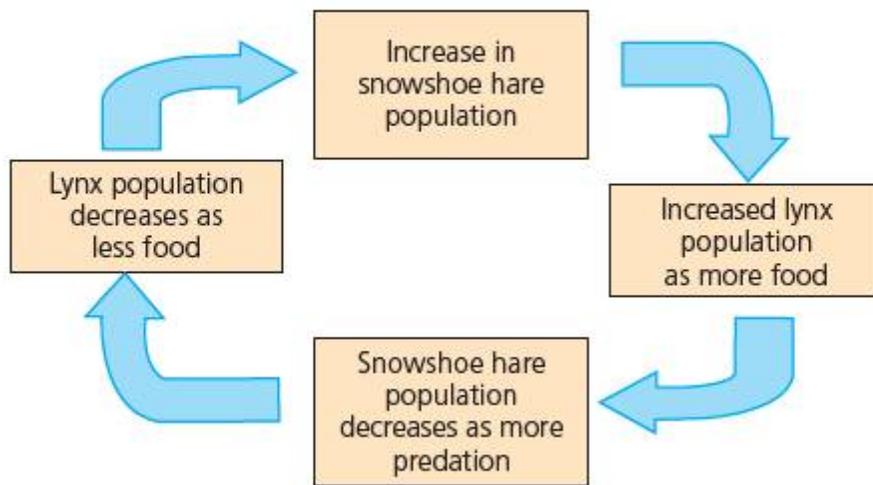
Figure 1.12 An example of negative feedback: predator–prey relationships between snowshoe hare and lynx in the boreal forest of North America

- All **feedback** links involve time lags.
- **Positive feedback** tends to amplify change away from equilibrium (Figure 1.13), whereas **negative feedback** mechanisms help to maintain stability (Figure 1.14).

Key word definitions

Feedback is when part of the output from a system returns as an input, so as to affect subsequent outputs.

Positive feedback is feedback that increases change; it promotes deviation away from an equilibrium.

Negative feedback is feedback that tends to counteract any deviation from equilibrium and promotes stability.

Albedo is the amount of light reflected by a surface.

Figure 1.13 Arctic ice melting leading to positive feedback through decreased planetary albedo
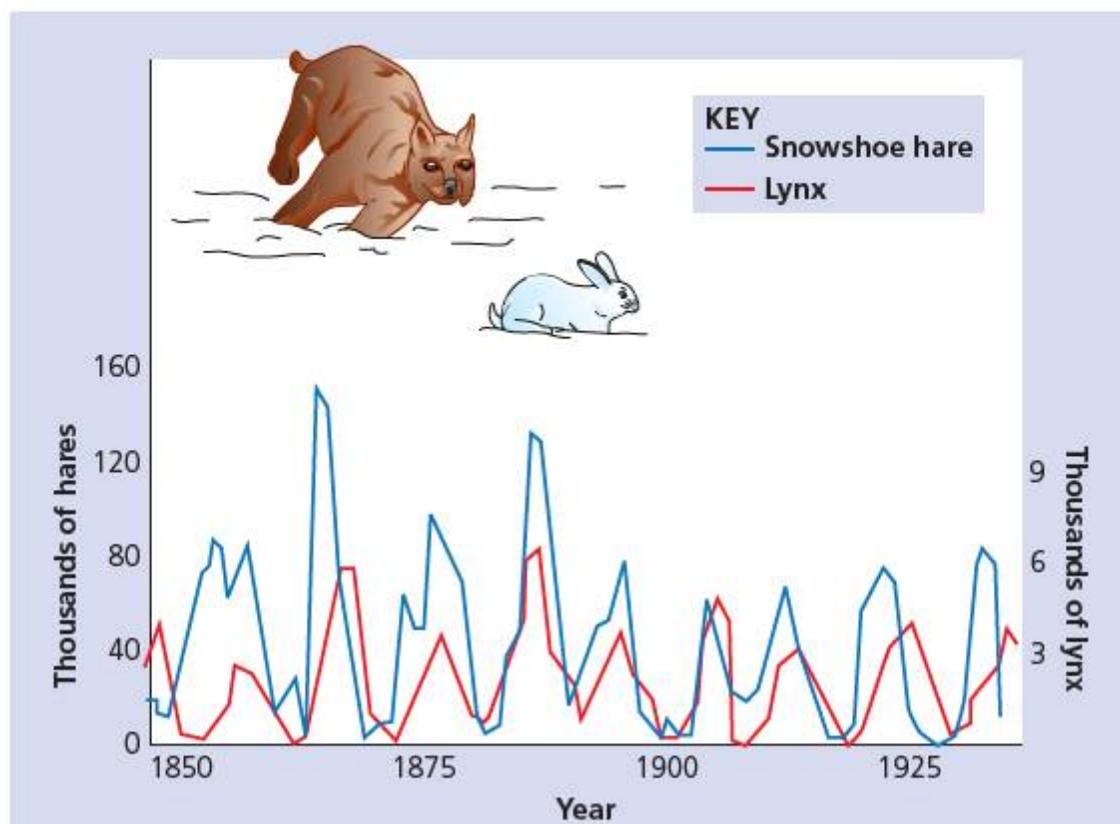
Figure 1.14 Predator–prey relationships

■ **QUICK CHECK QUESTIONS**

6   Compare negative and positive feedback mechanisms.
7   Give **two** examples of negative feedback, and **two** of positive feedback, which are relevant to the ESS course.

Models

Revised ☐

All **models** have strengths and limitations, as shown in Table 1.1.

Table 1.1 The advantages and disadvantages of models

Advantages	Disadvantages
■ They simplify complex systems and allow predictions to be made. ■ Inputs can be changed to see their effects and outputs, without having to wait for real events. ■ Results can be shown to other scientists and to the public. Models are easier to understand than detailed information about the whole system.	■ They might not be accurate and can be too simple. ■ They rely on the level of expertise of the people making them. ■ Different people can interpret them in different ways. ■ They may be used politically. ■ They depend on the quality of the data that go into the inputs. ■ Different models can show different outputs even if they are given the same data.

■ **QUICK CHECK QUESTIONS**

8   Describe the advantages and disadvantages of models.

Key word definition
A **model** is a simplified version of a system. It shows the flows and storages as well as the structure and workings.

EXAM PRACTICE

1 a State what type of system the Earth is and what the inputs and outputs are.   [3]

   b Describe the Gaia hypothesis, and how it can be applied to managing climate change.   [7]

   c Evaluate the usefulness of a global perspective for managing climate change effectively.   [4]

   d Scientists use computer simulations to model the effects of climate change. Define the term model.   [1]

   e Discuss the advantages and disadvantages of climate change models, and why there is uncertainty about
      predictions concerning global warming.   [5]

2 Sabah is a Malaysian state, located in northern Borneo. The natural vegetation is tropical rainforest, and coral
   reef is found around the coast. Borneo has oil reserves in offshore waters.

   a Tourism is an important economic activity in Sabah. Construct a model (diagram) that demonstrates the range
      of impacts tourism may have both directly and indirectly on Sabah ecosystems.   [4]

   b Define the term negative feedback.   [1]

   c Define the term positive feedback.   [1]

   d Explain why most ecosystems, such as rainforest, are negative feedback systems.   [1]

   e With the help of a diagram, describe the circulation of carbon in Borneo. On your diagram describe at least
      four storages and three processes.   [7]

3 a State, giving the reason, why natural systems are never 'isolated'.   [1]

   b Draw a flow diagram model to illustrate an example of negative feedback within an ecosystem.   [2]

Topic 2 The ecosystem

Structure

Biotic and abiotic components

The Earth's **biosphere** is a narrow zone, a few kilometres in thickness. It extends from the upper part of the atmosphere (where birds, insects and windblown pollen may be found) down to the deepest part of the Earth's crust to which living organisms venture. The biosphere is made up of **ecosystems** (see Figure 2.1), which have biotic and abiotic components:

- **Biotic** – the living part of an ecosystem, i.e. the **community**.
- **Abiotic** – the non-living part of an ecosystem, for example air, wind, temperature, water, soil, minerals, landscape, climate.

> **Key word definitions**
> The **biosphere** is that part of the Earth inhabited by organisms.
>
> An **ecosystem** is a community of interdependent organisms and the physical environment they inhabit.

> ■ **QUICK CHECK QUESTIONS**
> 1 Define the term *ecosystem*.
> 2 Identify **three** biotic and **three** abiotic components of an ecosystem near to where you live.

Figure 2.1 All ecosystems, such as tropical rainforest, include both living (e.g. animals, plants and fungi) and non-living components

> **Expert tip**
> Make sure you know and understand the difference between the terms *biotic* and *abiotic*: biotic refers to living components of the ecosystem and abiotic to non-living components.

Food chains and food webs

Figure 2.2 shows a typical food chain.

rainforest understorey leaves → sambar deer → Borneo python → crested serpent eagle

Figure 2.2 A rainforest food chain from Borneo

The rainforest food chain in Figure 2.2 contains the following trophic levels:
- **Producer** – rainforest understorey leaves
- **Primary consumer** – sambar deer (**herbivore**)
- **Secondary consumer** – Borneo python (**carnivore**)
- **Tertiary consumer** – crested serpent eagle (**top carnivore**)

Ecosystems contain many interconnected food chains that form **food webs** (see Figure 2.3). These show the complex feeding relationships that exist between species.

> **Common mistakes**
>
> Arrows in food chains represent energy flow and always run from left to right, towards the consumers, not towards the organisms being eaten
>
> You do not need to draw pictures of the plants and animals in food chains.

> **Key word definition**
> A **trophic level** is the position that an organism occupies in a food chain, or a group of organisms in a community that occupy the same position in food chains.
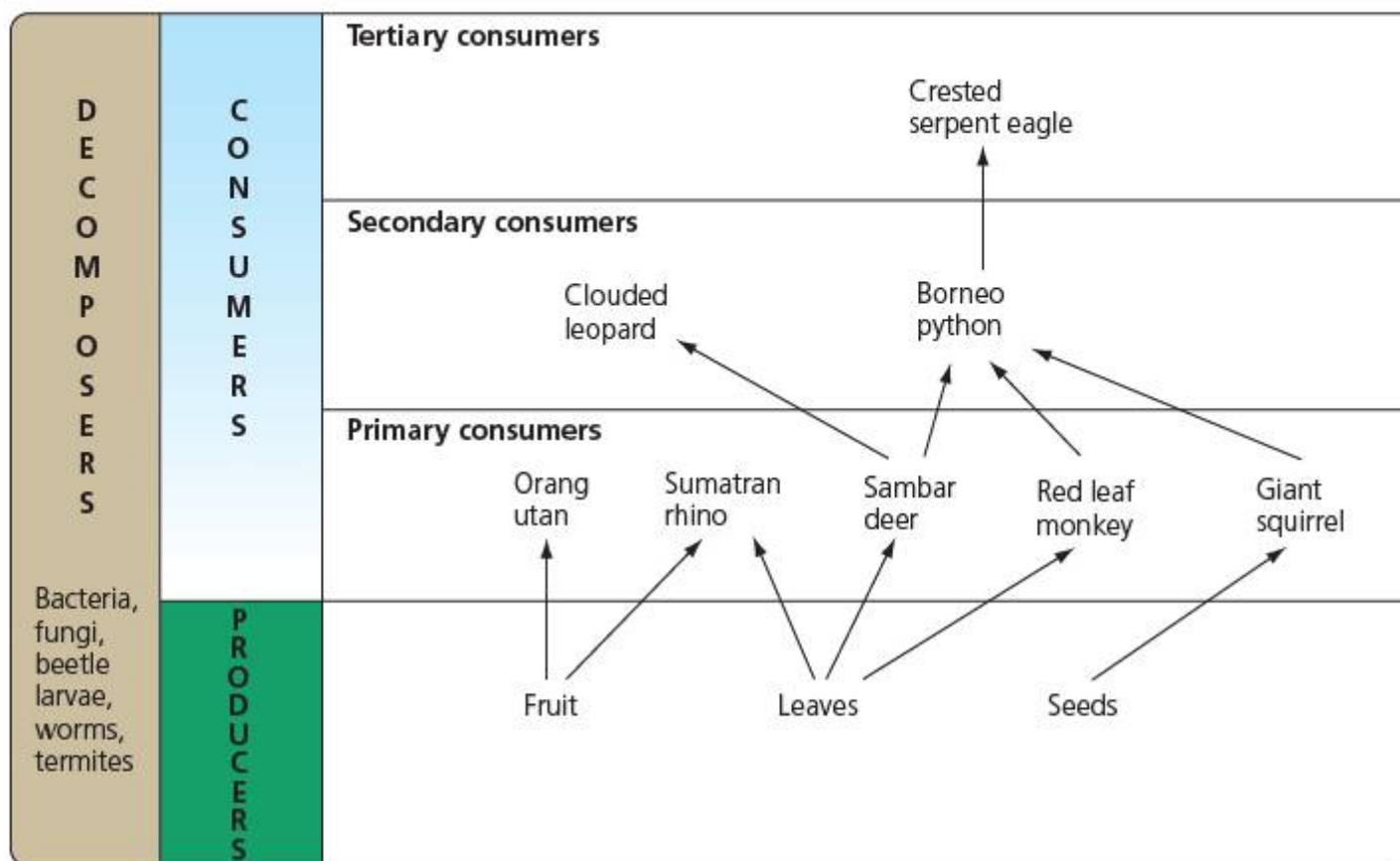
Figure 2.3 A rainforest food web from Borneo, showing trophic levels. Decomposers feed at each trophic level

> **Expert tip**
> If asked to draw a food chain, you should use specific organisms (e.g. 'Borneo python' rather than 'snake') from a specific ecosystem (e.g. 'Borneo rainforest' rather than 'forest').

> **Common mistake**
> If you are asked to draw a food chain, do not draw a food web, or vice versa. A food chain is linear, showing energy flow through an ecosystem. A food web shows the complex interactions between different food chains.

Pyramids of numbers, biomass and productivity

Pyramids are graphical models. They show quantitative differences between the trophic levels in an ecosystem.

Pyramids of numbers

A **pyramid of numbers** represents the number of organisms (producers and consumers) coexisting in an ecosystem (Figure 2.4).

Tertiary consumer	Badger
Secondary consumer	Hedgehog
Primary consumer	Slug
Producer	Lettuce
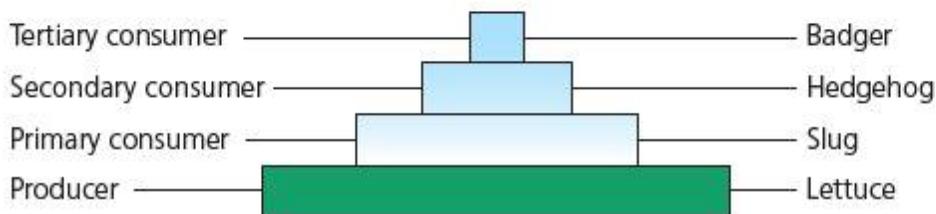
Figure 2.4 A pyramid of numbers

Table 2.1 The strengths and weaknesses of pyramids of numbers

Strengths	Weaknesses
■ A simple method of giving an overview of community structure. ■ Good for comparing changes in a number of individuals over time.	■ They do not take into account the size of organisms (see page 11). ■ Numbers can be too great to represent accurately. ■ Some animals feed at more than one trophic level (omnivores) and are therefore difficult to place.

Plotting a pyramid of numbers

Quantitative data for each trophic level are drawn to scale as horizontal bars, arranged symmetrically around a central axis.

Worked example

Construct a pyramid of numbers from the following data.

Species	Number of individuals
Lettuce	16
Slug	10
Hedgehog	6
Badger	4

■ Draw two axes on graph paper – the vertical axis should be located centrally on the paper (Figure 2.5 – axes are shown as dotted lines).
■ Data are plotted symmetrically around the vertical axis, for example there are 16 lettuces, and so the vertical bar is drawn with 8 units to the left and 8 to the right of the axis.
■ The height of the bars is arbitrary, but each bar should be the same height.
■ Label each trophic level.
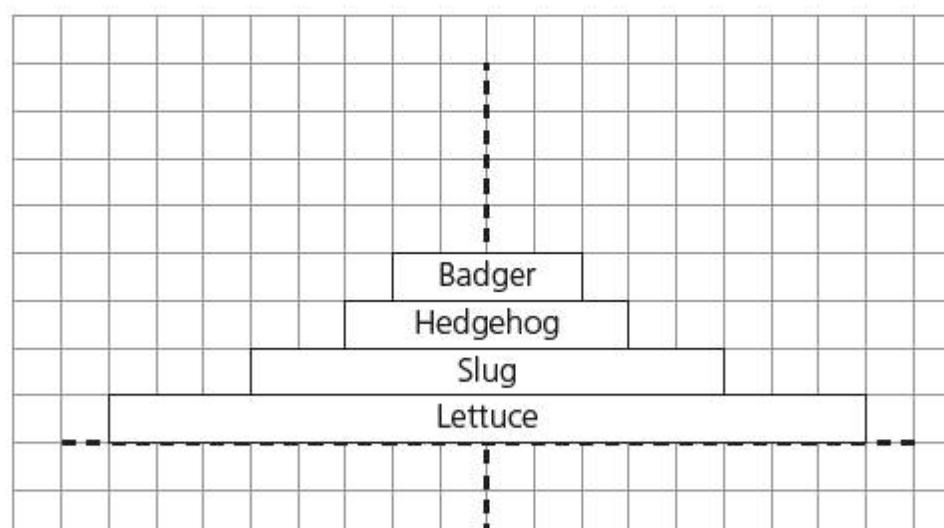
Figure 2.5 Plotting a pyramid of numbers

Pyramids of biomass

A **pyramid of biomass** shows the biological mass at each trophic level. Each trophic level is measured in grams of biomass per square metre (gm^{-2}) or kilograms per square metre (kgm^{-2}). Biomass can also be measured in units of energy (e.g. Jm^{-2}).

- Because energy decreases along food chains (second law of thermodynamics) biomass decreases along food chains, so pyramids become narrower towards higher trophic levels.
- Biomass is measured as dry weight (biological mass minus water).
- Both pyramids of numbers and pyramids of biomass represent storages.

Pyramids of numbers and biomass can be inverted, i.e. narrower at the base than at the next trophic level.

- If producers, such as an oak tree, are relatively large in size and so few in number, there will be fewer producers than primary consumers in a food chain (Figure 2.6).

Sparrowhawk
Thrush
Caterpillar
Oak tree
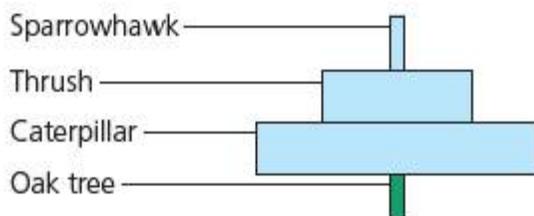
Figure 2.6 Pyramids of numbers do not take into account the size of the organisms, and can therefore be inverted

- Data for numbers and biomass pyramids are taken at a point in time. The biomass of the producers may be less than the consumers that feed on them – this also leads to the pyramid of biomass being inverted (Figure 2.7).

Mackerel
Sand eel
Zooplankton
Phytoplankton
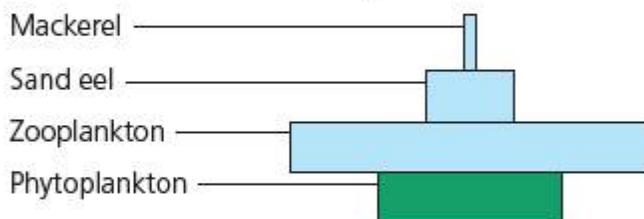
Figure 2.7 A pyramid of biomass for a north Atlantic seafood chain. Changes in feeding patterns and seasonal variations can lead to pyramids of biomass being inverted

If data are taken over a full year, the total biomass produced at the producer level will always be greater than the primary consumer level, and so on through the food chain, following the second law of thermodynamics. Such data are shown as **pyramids of productivity**. Pyramids of productivity refer to the flow of energy through trophic levels and always show a decrease in energy along the food chain. They are the only pyramid that is always pyramid shaped.

- Pyramids of numbers and biomass show the storage in the food chain at a given time, whereas pyramids of productivity show the rate at which those storages are being generated.
- Productivity is defined by the amount of new biomass created per unit area per unit time. It is measured in units of flow (e.g. $gm^{-2}yr^{-1}$ or $Jm^{-2}yr^{-1}$).

Expert tip

Biomass, measured in units of mass or energy (e.g. gm^{-2} or Jm^{-2}), should be distinguished from productivity, measured in units of flow (e.g. $gm^{-2}yr^{-1}$ or $Jm^{-2}yr^{-1}$).

Common mistake

Units are often not included when describing pyramids of biomass – these must not be forgotten (e.g. grams of biomass per square metre, gm^{-2}).

Pyramid structure and ecosystem functioning

Food chains and their respective pyramids can be changed by human activities:

- Because energy is lost through food chains, top carnivores tend to be few in numbers. Any reduction in the number of organisms lower down the food chain can therefore lead to carnivores being put at risk.
- Crop farming increases producers (base of pyramid) and decreases higher trophic levels.
- Livestock farming increases primary consumers and decreases secondary and tertiary consumers.
- Hunting removes top carnivores.
- Deforestation reduces the producer bar on biomass pyramids.
- The use of non-biodegradable toxins (such as DDT or mercury) can lead to reduction in the length of food chains:
  - The toxin accumulates in the body fat of consumers.
  - The toxin becomes increasingly concentrated as the consumers at each trophic level become fewer.
  - Organisms higher up the food chain live longer and so have more time to accumulate the toxin.
  - Top carnivores are at risk from poisoning from the toxin.

■ **QUICK CHECK QUESTIONS**

3   Explain the differences between pyramids of numbers, biomass and productivity.
4   Explain why pyramids of numbers and biomass can sometimes be inverted.
5   How can human activities affect pyramid structure? Give three examples.

Species, populations, habitats and niches

Figure 2.8 A population of zebra in an African savannah

Figure 2.9 A community of different animals in an African savannah. The savannah is the habitat in which the animals live

Expert tip

You need to be able to define the terms species, population, community, habitat and niche with reference to named local examples.

Key word definitions

A **species** is group of organisms that interbreed and are capable of producing fertile offspring.

A **population** is a group of organisms of the same species living in the same area at the same time, and which are capable of interbreeding.

A **community** is a group of populations living and interacting with each other in a common habitat.

A **habitat** is the environment in which a species normally lives.

A **niche** is a species' share of a habitat and the resources in it. An organism's ecological niche depends not only on where it lives but also on what it does.

Niches

- The niche is a complete description of a species – where, when and how it lives.
- Two species cannot share the same niche.
- Species with overlapping niches will compete with each other (see below).

Population interactions

Revised ☐

Ecosystems contain many different species, with different interactions being shown between populations:

- **Competition** between organisms can be:
  - □ **intraspecific** – competition between members of the *same* species
  - □ **interspecific** – competition between members of *different* species.
- **Parasitism** is a relationship where one organism – the **parasite** – benefits at the expense of another – the **host** – from which it derives its food.
- **Mutualism** (symbiosis) is an interaction in which both species derive benefit.
- **Predation** is when one animal (or sometimes a plant – see Figure 2.11) eats another animal.
- **Herbivory** is when an organism feeds on a plant.

Key word definition

Competition is a common demand by two or more organisms for a limited supply of a resource such as food, water, light, space, mates and nesting sites.

Expert tip

You need to know how interactions between species affect species' population dynamics, and how this can be shown graphically (e.g. see predator–prey interactions on page 6).
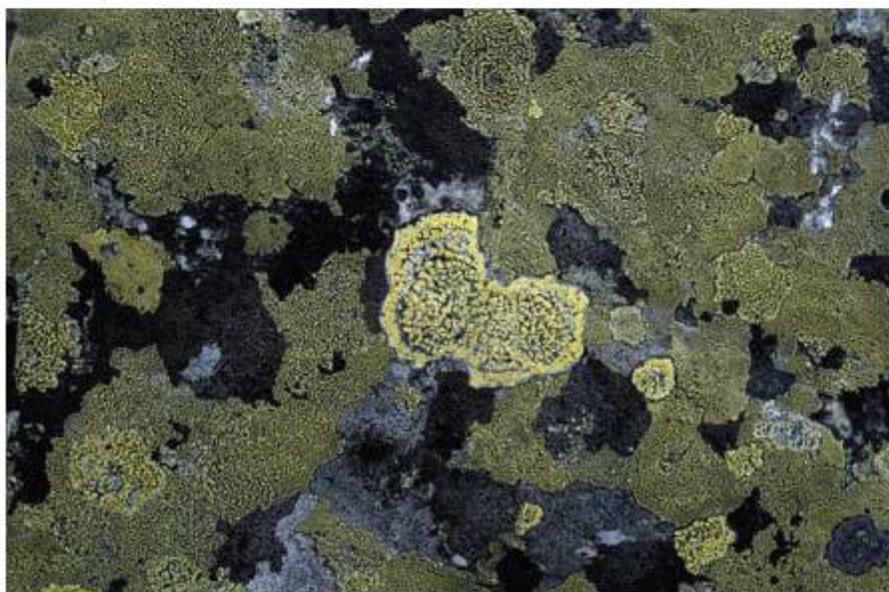
Figure 2.10 Lichens are a symbiotic relationship between a fungus and an alga

Figure 2.11 Pitcher plants feed on insects trapped in their highly adapted leaves (the pitchers)

EXAM PRACTICE

1 Using examples, distinguish between a *food chain* and a *food web*. [5]
2 Discuss how negative feedback processes control populations of a named parasite. [3]

Measuring abiotic components of the system

Abiotic factors include:

- **marine** – turbidity, salinity, pH, temperature, dissolved oxygen, wave action
- **freshwater** – turbidity, flow velocity, pH, temperature, dissolved oxygen
- **terrestrial** – temperature, light intensity, wind speed, particle size, slope, soil moisture, drainage, mineral content.

Expert tip

You need to be able to describe and evaluate methods for measuring at least three abiotic (physical) factors within an ecosystem, and state how these factors may vary with depth, time or distance.

Table 2.2 The measurement of abiotic factors in ecosystems

Abiotic factor	How is it measured?	Evaluation
Wind speed*	Anemometer	Gusty conditions can lead to large variations in data
Temperature+	Thermometer	Problems in data if temperature not taken from consistent depth
Light+	Lightmeter	Cloud cover changes light intensity, as does shading from plants or light-meter operator
Flow velocityx	Flowmeter	Readings must be taken from same depth; water flow can vary due to rainfall/ice melt
Wave action†	Dynamometer	Changes in wave strength during a day and over a monthly period affect results
Turbidity†	Secchi disc	Reflections off water reduce visibility; measurements are subjective
Dissolved oxygenx	Oxygenmeter	Possible contamination from oxygen in air when using oxygenmeter
Soil moisture*	Evaporate water; soil moisture probes	If soil is too hot when evaporating water, organic content can also burn off

Type of ecosystem where technique is mainly used: *terrestrial; ˣfreshwater; †marine; +all three

Figure 2.12 Using an anemometer to measure wind speed in a shingle ridge succession

Figure 2.13 Using a flow meter to measure water speed in a forest river

Key word definition
An **abiotic factor** is a non-living, physical factor that can influence an organism or ecosystem – for example, temperature, sunlight, pH, salinity or precipitation.

Abiotic factors can vary from day to day and season to season. Electronic data-loggers overcome many of the limitations shown by abiotic measuring devices:

- They provide continuous data over a long period of time.
- They make data more representative of the area being sampled.
- More data can be collected, making results more reliable.

Common mistake

'Climate' and 'temperature' are sometimes used interchangeably. These terms are not the same: climate includes rainfall, humidity and wind speed as well as temperature.

■ **QUICK CHECK QUESTIONS**

8 Identify an abiotic factor found in a freshwater ecosystem. Outline how you would measure this factor.
9 Identify an abiotic factor found in a marine ecosystem. Outline how this factor would vary with depth.
10 Identify an abiotic factor found in a terrestrial ecosystem. Evaluate the technique used to measure this factor.

Expert tip

If you are using sampling methods as examples in exam questions, use specific examples and avoid vague answers. If you have been on a field trip, knowledge of techniques gained through fieldwork should be used.

EXAM PRACTICE

3 a Name an ecosystem you have studied and state **one** abiotic factor
       you can measure.   [1]

   b Outline how you would measure changes in the abiotic factor
       over time.   [2]

   c Explain why differences in the abiotic factor named in a might affect
       diversity between two sites.   [2]

4 With the help of examples, suggest a research question that would
   connect the abiotic and biotic components of an ecosystem.   [2]

Measuring biotic components of the system

Revised ☐

Key word definition
A **biotic factor** is a living, biological process that can influence an
organism or ecosystem – for example, predation, parasitism, disease or
competition.

Dichotomous keys

Revised ☐

In ecological projects, it is important to correctly identify organisms being
studied. This is done using **dichotomous keys**. Each key is organised in steps,
with two options given at each step. The two options identify contrasting
features of the species.

Expert tip
Keys can also be shown as a diagram,
with branches representing each step.

Worked example

Construct a key for the following animals: spider, beetle, monkey, gibbon,
rhinoceros, eagle, snake, frog, leopard, butterfly, kangaroo and dolphin.

1	a Animal is a vertebrate	*go to 4*
	b Animal is an invertebrate	*go to 2*
2	a Animal has fewer than 8 legs	*go to 3*
	b Animal has 8 legs	**spider**
3	a Animal has two hardened wing cases	**beetle**
	b Animal does not have modified wings	**butterfly**
4	a Animal is warm blooded (endothermic)	*go to 6*
	b Animal is cold blooded (ectothermic)	*go to 5*
5	a Animal has legs	**frog**
	b Animal does not have legs	**snake**
6	a Animal is adapted for life in water	**dolphin**
	b Animal is not adapted for life in water	*go to 7*
7	a Animal has wings	**eagle**
	b Animal does not have wings	*go to 8*
8	a Animal has a placenta	*go to 9*
	b Animal does not have a placenta	**kangaroo**
9	a Animal has fur	*go to 10*
	b Animal does not have fur	**rhinoceros**
10	a Animal has claws on feet	**leopard**
	b Animal does not have claws on feet	*go to 11*
11	a Animal has a tail	**monkey**
	b Animal does not have a tail	**gibbon**

Limitations of keys include:
- The organism might not be in the key.
- Terminology can be difficult.
- There might not be a key available for the organisms under investigation.
- Some features cannot be easily established in the field – for example, whether an animal has a placenta or not, or whether an animal is endothermic or ectothermic.

Methods for estimating the abundance of organisms

Lincoln index

This technique is known as the capture–mark–release–recapture method. It is used for estimating the population size of mobile animals.
- Organisms are captured, marked, released and then recaptured.
- Marking varies according to the type of organism. For example, wing cases of insects can be marked with pen, snails with paint, and fur clippings used for mammals.
- Markings must be difficult to see – high visibility increases predation risk.
- The number of individuals of a species are recorded at each stage.
- The total population size is estimated using the following equation:

$$N = \frac{n_1 \times n_2}{m}$$

Where: N = total population of animals in the study site
n_1 = number of animals captured (marked and released) on first day
n_2 = number of animals recaptured on second day
m = number of marked animals recaptured on second day

> **Expert tip**
>
> You need to memorise the Lincoln index formula as it is not given in exams.

Quadrat methods

Quadrats are used for estimating the abundance of plants and non-mobile animals.
- **Percentage frequency** is the percentage of quadrats in an area in which at least one individual of the species is found.
- **Percentage cover** is the proportion of a quadrat covered by a species, measured as a percentage (Figure 2.14). It is worked out for each species present. Estimates can be made by dividing the quadrat into a 10×10 grid (100 squares), where each square is 1% of the total area covered.
- **Population density** is the number of individuals of each species per unit area. It is calculated by dividing the number of organisms by the total area of the quadrats.

Figure 2.14 A quadrat being used to estimate percentage cover of seaweed on a rocky shore

The sampling system used depends on the areas being sampled:
- **Random sampling** is used if the same habitat is found throughout the area.
- **Stratified random sampling** is used in two areas different in habitat quality.
- **Systematic sampling** is used along a **transect** where there is an environmental gradient.

Method for estimating the biomass of trophic levels

Revised ☐

Biomass is calculated to indicate the total energy within a trophic level.
- Biomass is a measure of the organic content of organisms.
- Water is not an organic molecule, and its amount varies from organism to organism, so water is removed before biomass is measured. This is called **dry weight biomass**.
- One criticism of the method is that it involves the killing of living organisms (although not all the organisms in an area need to be sampled – see below).
- Problems exist with measuring biomass of very large plants such as trees, and with roots and underground biomass.

> **Key word definition**
> **Biomass** is the mass of organic material in organisms or ecosystems, usually stated per unit area.

Calculating dry weight biomass

To obtain quantitative samples, biological material is dried to constant weight:
- The sample is weighed in a container of known weight.
- The sample is put in a hot oven (80°C).
- After a specific length of time the sample is reweighed.
- The sample is put back in the oven.
- This is repeated until the same mass is recorded from two successive readings.
- No further loss in mass indicates that water is no longer present.

Biomass is recorded per unit area (e.g. per metre squared) so that trophic levels can be compared. Not all organisms in an area need to be sampled:
- The mass of one organism, or the average mass of several organisms, is taken.
- This mass is multiplied by the total number of organisms to estimate total biomass.
- This is called an **extrapolation** technique.

> **Expert tip**
> To estimate the biomass of a primary producer, all the vegetation, including roots, stems and leaves, is collected within a series of 1 m × 1 m quadrats. The dry weight method is carried out and average biomass calculated.

> ■ **QUICK CHECK QUESTIONS**
> 11 Describe and evaluate methods for measuring **three** abiotic factors in a forest ecosystem.
> 12 Explain the difference between percentage frequency and percentage cover.
> 13 Which data are needed to estimate the size of an animal population? Write the equation needed to calculate population size.
> 14 Explain how biomass is calculated.

Diversity and the Simpson's diversity index

Revised ☐

Species diversity refers to the number of species and their relative abundance (see Topic 4). It can be calculated using **diversity indices**.

Species diversity can be calculated using the **Simpson's diversity index**, using the equation:

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$

Where:
> D = Simpson's index
> N = total number of organisms of all species found
> n = number of individuals of a particular species
- Index values are relative to each other and not absolute, unlike measures of, say, temperature, which are on a fixed scale.

> **Key word definitions**
> **Diversity** is a generic term for heterogeneity (i.e. variation or variety). The scientific meaning of diversity becomes clear from the context in which it is used; it can refer to heterogeneity of species or habitat, or to genetic heterogeneity.
>
> A **diversity index** is a numerical measure of species diversity calculated by using both the number of species (species richness) and their relative abundance.

- Comparisons can be made between areas containing the same type of organism in the same ecosystem.
- A high value of D suggests a stable and ancient site, where all species have similar abundance (or 'evenness').
- A low value of D could suggest disturbance through, say, logging, pollution, recent colonisation or agricultural management, where one species may dominate.

Worked example

The table below contains data from two different habitats. Total number of species (= 'species richness') and total number of individuals is the same in each case. Calculate the diversity of both habitats and comment on the differences between the habitats.

Species found	Number found in habitat X	Number found in habitat Y
A	10	3
B	10	5
C	10	2
D	10	36
E	10	4
Number of species =	5	5
Number of individuals =	50	50

The Simpson's index must be calculated for each habitat. This can be done using a table to calculate components of the index:

Species	Numbers (n) found in habitat X	$n(n-1)$	Numbers (n) found in habitat Y	$n(n-1)$
A	10	10(9) = 90	3	3(2) = 6
B	10	10(9) = 90	5	5(4) = 20
C	10	10(9) = 90	2	2(1) = 2
D	10	10(9) = 90	36	36(35) = 1260
E	10	10(9) = 90	4	4(3) = 12
	$\Sigma n(n-1)$	450	$\Sigma n(n-1)$	1300

Species diversity for each habitat:
- Habitat X:

$$D = \frac{50(49)}{450} = \frac{2450}{450} = 5.44$$

- Habitat Y:

$$D = \frac{50(49)}{1300} = \frac{2450}{1300} = 1.88$$

What do these values say about each habitat?
- Greater 'evenness' between species in habitat X.
- Less competition due to non-overlapping niches in habitat X.
- One species does not dominate in X, reflecting greater habitat complexity/more niches.
- Habitat Y – less complex with fewer/overlapping niches, where one species can dominate, leading to lower diversity.

EXAM PRACTICE

5 Outline and evaluate a method for estimating the abundance of a named plant species in a named ecosystem. [3]

6 Describe and evaluate a method for estimating the abundance of rhinos in an African national park. [4]

7 a Explain why abundance of organisms might be of importance in estimating the diversity of an ecosystem. [2]

   b Explain how you would compare the diversity of **two** different ecosystems. [5]

8 a Calculate the Simpson's diversity index for habitat B using data from the table below. Use the formula:

$$D = \frac{N(N-1)}{\Sigma n(n-1)}$$
[2]

SPECIES FOUND	NUMBER OF INDIVIDUALS FOUND IN EACH HABITAT				
	HABITAT A	HABITAT B	HABITAT C	HABITAT D	HABITAT E
Species 1	25	50	80	97	100
Species 2	25	30	10	1	0
Species 3	25	15	5	1	0
Species 4	25	5	5	1	0
Simpson's index (*D*)	4.13		1.37	1.04	1.00

   b i) Describe and explain the differences between the habitats shown in the table.

      ii) Suggest reasons for the different values of Simpson's index recorded in different habitats. [4]

Biomes

<div style="text-align: right">Revised ☐</div>

Biome distribution depends on levels of insolation (sunlight), temperature and precipitation (rainfall).

> **Key word definition**
> A **biome** is a collection of ecosystems sharing similar climatic conditions – for example, tundra, tropical rainforest, desert.

Table 2.3 Biome distribution, structure and productivity

Biome	Distribution/climate	Structure	Relative productivity
Tropical rainforest	Found between the Tropics of Cancer and Capricorn (23.5° N and S of equator) High rainfall (over 2500 mm yr⁻¹), sunlight and temperature No seasons, so consistent light and temperature	Has a complex structure with a number of layers from ground level to canopy Has emergent trees up to 50 m and lower layers of shrubs and vines Dense canopy means that only 1% of sunlight may reach the floor; shrub layer may be sparse with most productivity in the canopy Soils are thin and nutrient poor	Very high: mean net primary productivity (NPP) = $2.20\,kg\,m^{-2}\,yr^{-1}$
Desert	In bands at latitudes of approximately 15–30° N and S of equator Low rainfall (under 250 mm yr⁻¹); high sunlight; very hot in daytime and cold at night	Vegetation is scarce, with an absence of tall trees Many xerophytic plants (i.e. adapted to dry or desert conditions) such as cacti Soil has low water-holding capacity and low fertility Soil erodes easily in the wind Animals are adapted to desert conditions	Very low: mean NPP = $0.003\,kg\,m^{-2}\,yr^{-1}$

Biome	Distribution/climate	Structure	Relative productivity
Tundra	High latitudes, adjacent to ice margins Low temperatures; low precipitation; seasonal sunlight and short day length	Has a simple structure Vegetation is low scrub and grasses Vegetation forms a single layer An absence of tall trees Frozen permafrost and soil limit productivity	Low: mean NPP = $0.14\,kg\,m^{-2}\,yr^{-1}$
Temperate forest	Found between 40° and 60° N of equator Rainfall sufficient to establish forest (500–1500 mm yr^{-1}) rather than grassland Temperatures and light intensity vary with season	May contain seasonal (deciduous) trees, evergreen (e.g. coniferous trees) or both; evergreen trees have thicker leaves or needles to protect against the cold; deciduous trees lose their leaves in winter Less complex structure than rainforest, often dominated by one species Some layering of forest, although tallest trees grow no more than around 30 m The lower and less dense canopy than rainforest means more light reaches forest floor – growth of rich shrub layer (e.g. brambles, grasses, bracken and ferns)	Medium: mean NPP = $1.20\,kg\,m^{-2}\,yr^{-1}$

■ **QUICK CHECK QUESTIONS**

16 State **two** factors that influence productivity.
17 Explain how abiotic factors determine the distribution of tropical rainforest.
18 Compare the structure of tundra and a **named** local biome.

Expert tip

You need to be able to discuss the distribution, structure and relative productivity of tropical rainforests, deserts, tundra and one other biome.

EXAM PRACTICE

9 Explain how different limiting factors will determine productivity in **two** contrasting biomes. [4]
10 Explain why productivity in tundra is low. [3]
11 Tropical rainforest has a mean NPP of $2.20\,kg\,m^{-2}\,yr^{-1}$, and tundra $0.14\,kg\,m^{-2}\,yr^{-1}$. When NPP per kg biomass per year is calculated, tropical rainforest has a value of 0.049, and tundra a value of 0.233. Compare and explain these data. [4]

Key word definition
Latitude is the angular distance from the equator (north or south of it) as measured from the centre of the Earth (usually in degrees).

Function

Revised ☐

The role of producers, consumers and decomposers

Revised ☐

Producers make their own food (glucose) and convert (fix) inorganic molecules into organic molecules (see Figure 2.15). Plants, algae and some bacteria are producers.
■ **Photoautotrophs** (e.g. all plants) convert sunlight energy into chemical energy.
■ **Chemoautotrophs** (e.g. nitrifying bacteria) use chemical energy from oxidation reactions to create glucose.

Producers support all ecosystems through constant input of energy and new biomass.

Consumers do not contain photosynthetic pigments (e.g. chlorophyll) and so cannot make their own food. They must obtain the energy, minerals and nutrients they need by eating other organisms. They are also known as **heterotrophs**. They pass energy and biomass through a food chain from producers through to top carnivores.

Decomposers obtain their food from the breakdown of dead organic matter. They include **bacteria** and **fungi**. Decomposers release nutrients ready for absorption by producers (Figure 2.15). They feed at each trophic level of a food chain and are essential for recycling matter, including elements such as carbon and nitrogen, in ecosystems.

Producers

| Elements (e.g. carbon, nitrogen) in the environment (*inorganic molecules*) | Elements in biomass (*organic molecules*) |
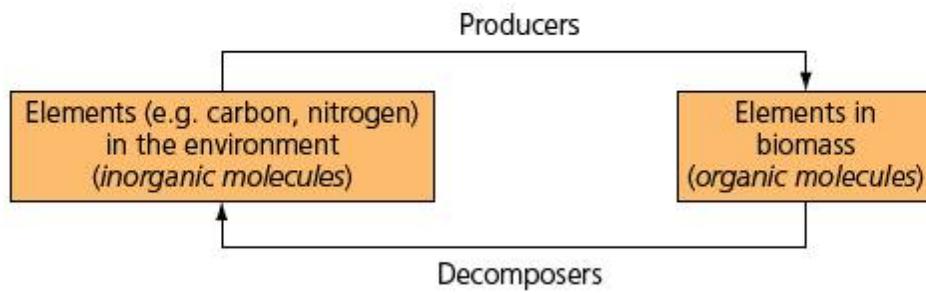
Decomposers

Figure 2.15 The role of producers and decomposers in ecosystems

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■ **QUICK CHECK QUESTIONS**

19 Explain the differences between producers and consumers.
20 Explain the role of producers and decomposers in ecosystems.

Photosynthesis and respiration

Revised

Photosynthesis (Figures 2.16 and 2.17) is the transformation of light energy into the chemical energy of organic matter:

■ Carbon dioxide, water, chlorophyll and certain visible wavelengths of light (e.g. red and blue) are used to produce organic matter (glucose) and oxygen.
■ The process is controlled by enzymes – warmer conditions increase the rate of photosynthesis up to an optimum temperature.

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$$
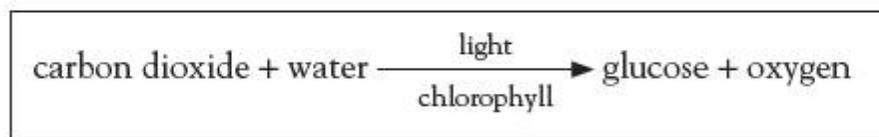
Figure 2.16 The word equation for photosynthesis

light

$6CO_2$

chlorophyll → $C_6H_{12}O_6 + 6O_2$
(glucose)

$6H_2O$
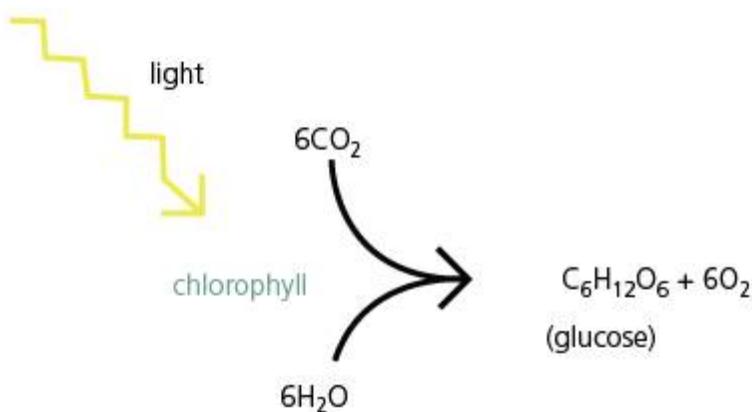
Figure 2.17 The chemical reactions of photosynthesis

Respiration (Figure 2.18) is the breakdown of glucose using oxygen, releasing carbon dioxide, water and energy:

■ Stored chemical energy is transformed into kinetic energy and heat.
■ Respiration carried out using oxygen is called aerobic respiration.
■ Respiration carried out without oxygen is called anaerobic respiration, where carbon dioxide and other waste products are formed.
■ Energy is released in a form available for use by living organisms, but is ultimately transformed into heat (second law of thermodynamics).

Expert tip

Although respiration involves the release of energy, energy is not included in the word equation.

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} (+ \text{ENERGY})$$
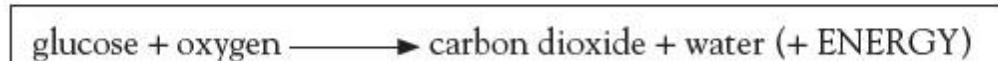
Figure 2.18 The word equation for respiration

Table 2.4 Input, outputs and transformations of photosynthesis and respiration

Process	Inputs	Outputs	Transformations
Photosynthesis	Sunlight energy	Glucose	Light energy into stored chemical energy
	Carbon dioxide	Oxygen	
	Water		
Respiration	Glucose	Carbon dioxide	Stored chemical energy into kinetic energy and heat
	Oxygen	Water	
		Energy	

Transfer and transformation of energy

Revised ☐

Energy enters the ecosystem as sunlight energy, is transformed into chemical energy/biomass, is then transferred between trophic levels by consumers and ultimately leaves the ecosystem as heat energy.
- Very little of the available sunlight energy is used to make new biomass.
- Producers are inefficient at converting sunlight energy into stored chemical energy (see Figure 2.19).

GPP – gross primary production

NPP – net primary production
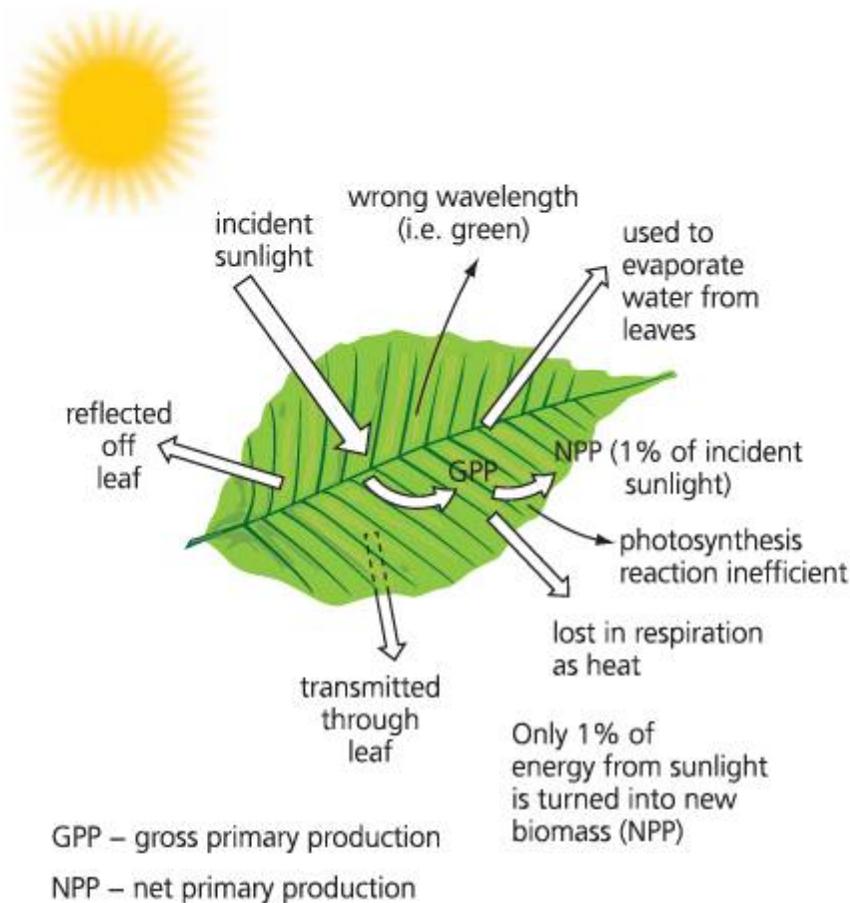
Figure 2.19 The conversion of sunlight energy into new biomass is inefficient

In a food chain there is a loss of chemical energy from one trophic level to another. **Ecological efficiency** is the percentage of energy transferred from one trophic level to the next.
- Efficiencies of transfer are low and account for energy loss, varying from 5% to 20% with an average of 10%.
- Energy is lost through movement, inedible parts (e.g. bone, teeth, fur), faeces, and ultimately as heat through the inefficient energy conversions of respiration (second law of thermodynamics).
- Overall there is the conversion of light to heat energy by an ecosystem.

- Energy is converted from one form to another but cannot be created or destroyed (first law of thermodynamics).
- Inputs of the system as a whole, and of any individual trophic level, equal the outputs.
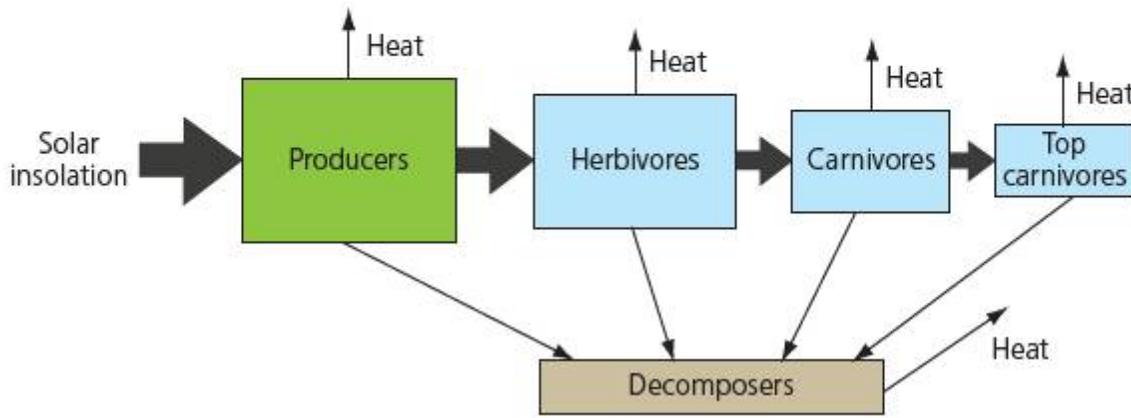
Figure 2.20 Diagram showing the transfers and transformations of energy as it flows through an ecosystem. Arrows showing flows of energy vary in width, proportional to the amount of energy being transferred

Transfer and transformation of materials within an ecosystem

Materials such as carbon, nitrogen and water are cycled within an ecosystem. These cycles involve transfer and transformation processes including the conversion of organic and inorganic storages (see Figure 2.15).

The cycles shown here (Figures 2.21, 2.22 and 2.24) illustrate the different ways cycles can be represented.

Carbon cycle
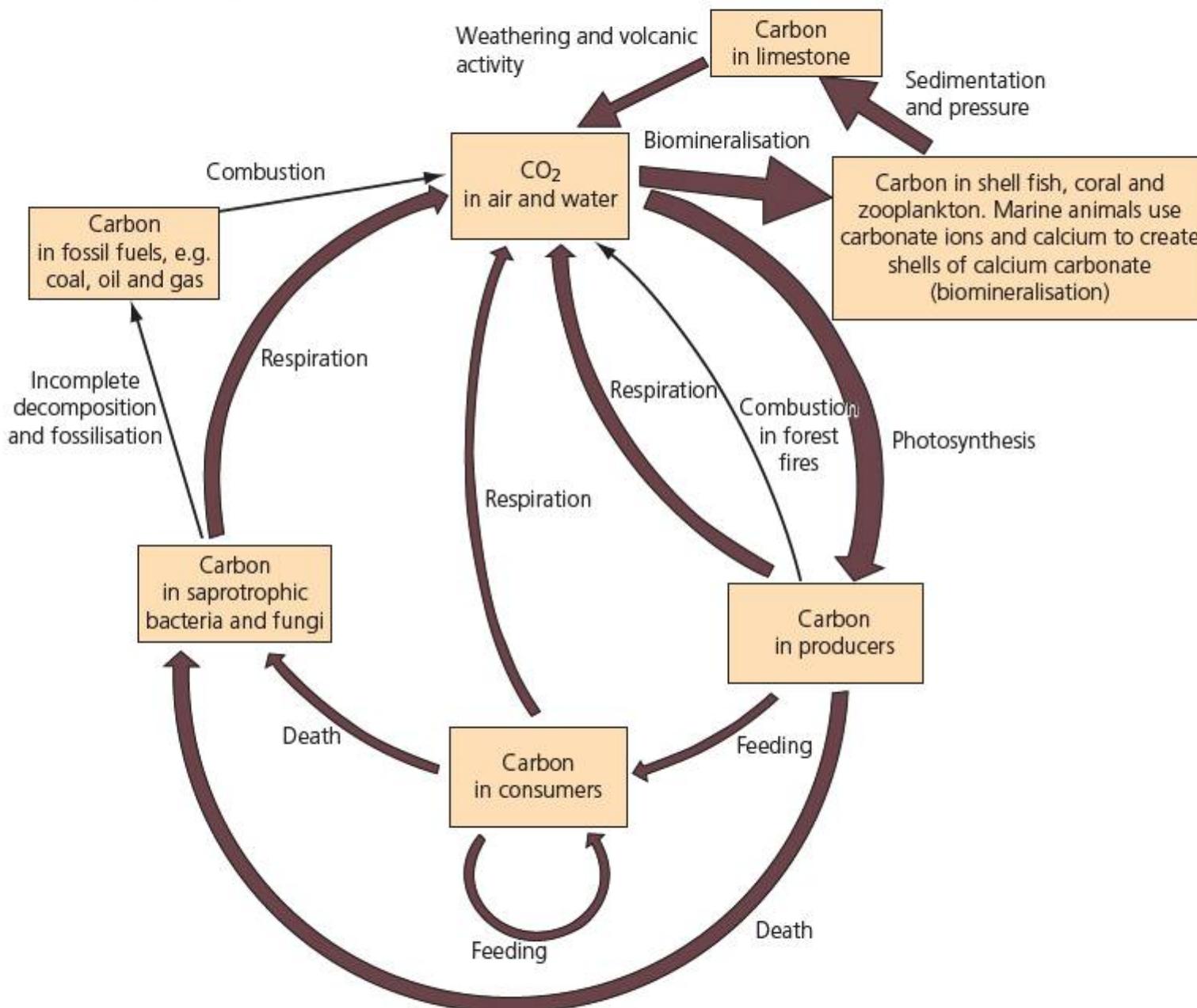
Figure 2.21 The carbon cycle

Table 2.5 Transfers and transformation processes in the carbon cycle

Transfers	Transformations
Feeding on plant material by herbivores	Photosynthesis (CO_2 into glucose)
Feeding on herbivores by carnivores	Respiration (organic matter into CO_2)
Feeding on dead organisms by decomposers	Combustion (organic matter into CO_2)
CO_2 from atmosphere dissolves in rainwater	Biomineralisation (CO_2 into calcium carbonate)
CO_2 from atmosphere dissolves in oceans	Incomplete decomposition and fossilisation

Nitrogen cycle
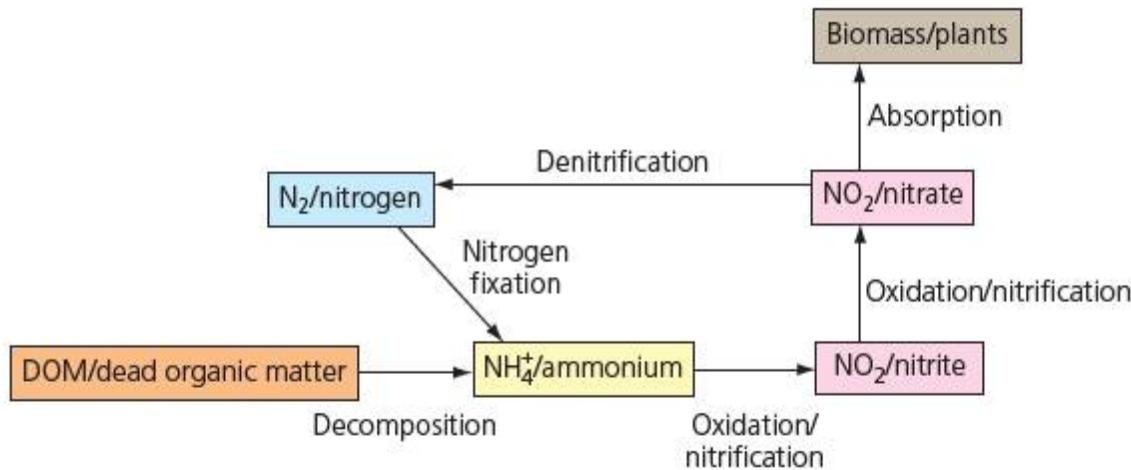
Figure 2.22 The nitrogen cycle

The nitrogen cycle involves four different types of bacteria:
- **Nitrogen fixing** – nitrogen from atmosphere converted into ammonium ions.
- **Nitrifying** – ammonium ions converted into nitrite and then nitrate.
- **Denitrifying** – nitrates converted into nitrogen.
- **Decomposers** – break down organic nitrogen into ammonia – **deamination**.

Table 2.6 Transfers and transformation processes in the nitrogen cycle.

Transfers	Transformations
Feeding on plant material by herbivores	Nitrogen fixation
Feeding on herbivores by carnivores	Nitrification
Feeding on dead organisms by decomposers	Denitrification
Absorption of nitrates by plants	Deamination

Nutrient cycles

Nutrient cycles can be drawn as simple diagrams, showing the storages and flows of nutrients. Figure 2.23 shows the differences in storages and flows of nutrients in two contrasting ecosystems.
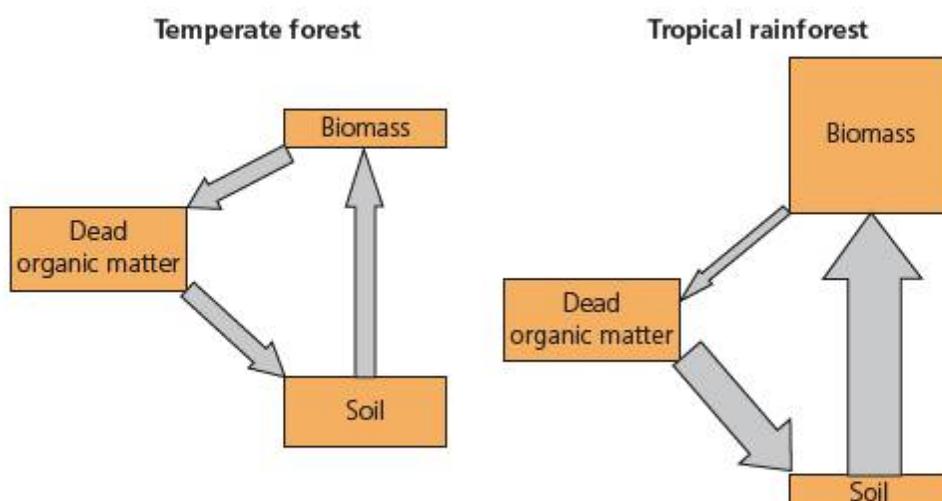
Figure 2.23 Diagrams showing the major nutrient flows and storages in two different ecosystems. The size of the boxes and width of the arrows are proportional to the size of the storages and flows they represent

Water cycle

The **hydrological cycle** is the cycle of water between the atmosphere, lithosphere and biosphere. (All figures are in $10^3 \, m^3 \, yr^{-1}$.)
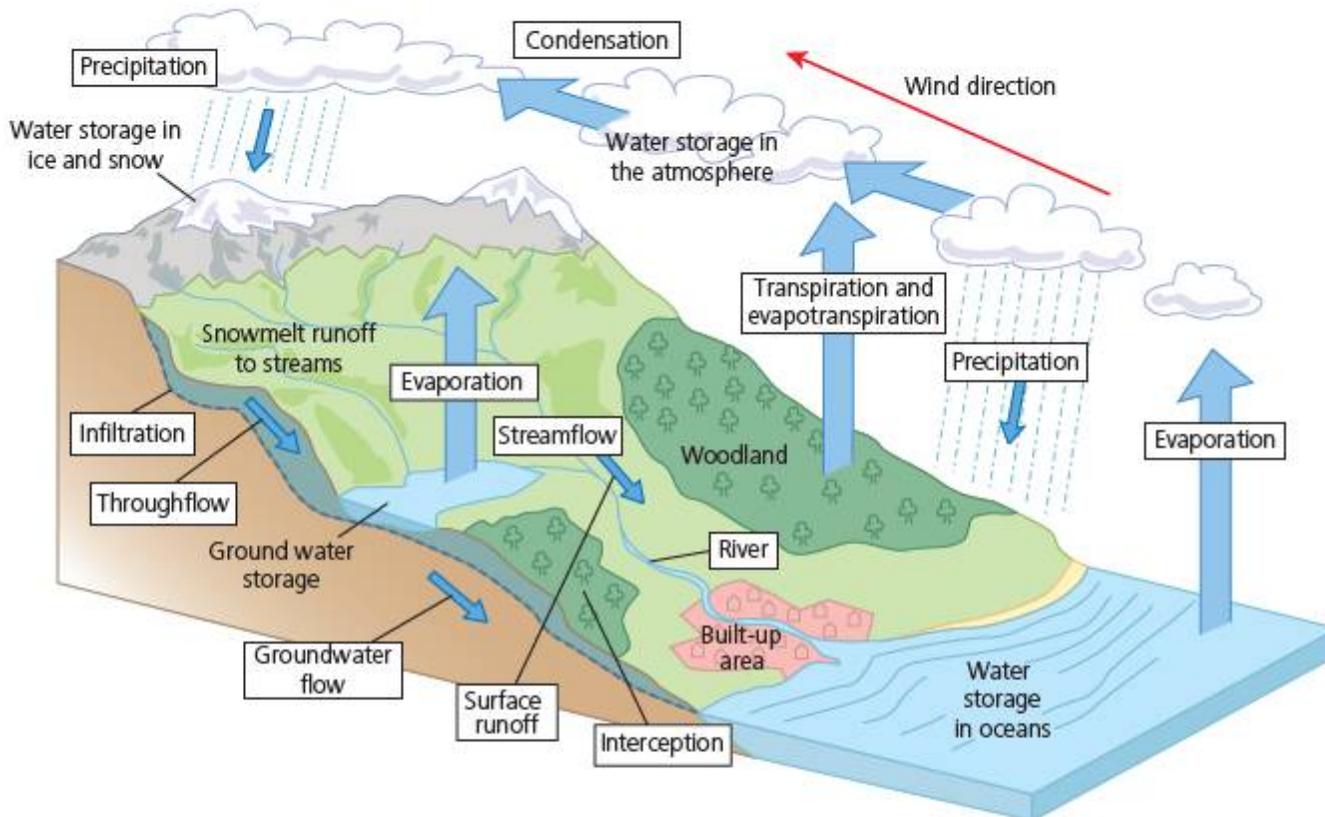
Figure 2.24 The hydrological cycle

Table 2.7 Transfers and transformation processes in the water cycle

Transfers	Transformations
Precipitation	Evaporation
Runoff	Transpiration
Absorption by plants	Condensation

■ QUICK CHECK QUESTIONS

21 Explain the differences between photosynthesis and respiration. Use the terms *transfer* and *transformation* in your answer.
22 Outline the transfers and transformations of energy as it flows through an ecosystem.
23 Explain the term *ecological efficiency*.
24 State **two** transfers and **two** transformations in the carbon cycle.
25 Using a diagram, show how nitrogen is cycled through an ecosystem.
26 Outline the transfers and transformations of water as it cycles through an ecosystem.

Gross productivity, net productivity, primary productivity and secondary productivity

Revised ☐

Key word definitions

Gross productivity (GP) is the total gain in energy or biomass per unit area per unit time, which could be through photosynthesis in primary producers or absorption in consumers.

Net productivity (NP) is the gain in energy or biomass per unit area per unit time remaining after allowing for respiratory losses (R).

Primary productivity is the gain by producers in energy or biomass per unit area per unit time. This term could refer to either gross or net primary productivity.

Secondary productivity is the biomass gained by consumers (heterotrophic organisms), through feeding and absorption, measured in units of mass or energy per unit area per unit time.

Expert tip

Productivity is production per unit time. You must include units when defining it.

Gross primary productivity and net primary productivity

Key word definitions
Gross primary productivity (GPP) is the total gain in energy or biomass per unit area per unit time fixed by photosynthesis in green plants.

Net primary productivity (NPP) is the gain by producers in energy or biomass per unit area per unit time remaining after allowing for respiratory losses (R). This is potentially available to consumers in an ecosystem.

$$NPP = GPP - R$$
(where R = respiratory loss)

Figure 2.25 Equation for net primary productivity

NPP is the rate at which plants accumulate new biomass. It represents the actual store of energy contained in potential food for consumers. NPP is easier to calculate than GPP as biomass is simpler to measure than the amount of energy fixed into glucose.

Gross secondary productivity and net secondary productivity

Key word definition
Gross secondary productivity (GSP) is the total gain by consumers in energy or biomass per unit area per unit time through absorption.

- Much of the biomass eaten by consumers is absorbed (e.g. through the guts of animals) and converted into new biomass within cells.
- Consumers do not use all the biomass they eat.
- Some energy passes out in faeces and excretion.
- Only the biomass remaining can be used by the consumer (GSP).

Key word definition
Net secondary productivity (NSP) is the gain by consumers in energy or biomass per unit area per unit time remaining after allowing for respiratory losses (R).

- Some of the biomass absorbed by animals is used in respiration.
- The energy released is used to support life processes.
- The remaining energy is available to form new biomass (NSP).
- This new biomass is then available to the next trophic level.

$$GSP = food\ eaten - faecal\ loss$$
$$NSP = GSP - R$$
(where R = respiratory loss)

Figure 2.26 Equations for GSP and NSP

■ QUICK CHECK QUESTIONS
27 Distinguish between primary productivity and secondary productivity.
28 Outline how you would calculate net primary productivity.
29 Explain the differences between gross secondary productivity and net secondary productivity.

EXAM PRACTICE

12 a Suggest how the differences in the size of comparable storages of the two ecosystems shown in Figure 2.23 (page 24) can be explained in terms of their different climates. [7]

b Draw a labelled flow diagram showing the flows and storages of inorganic nitrogen that normally occur within soil. Show on your diagram how these flows provide a link between the storages of dead organic matter and biomass. [3]

13 Explain the relationship between climate and net primary productivity in two contrasting biomes you have studied. [7]

14 State the **two** factors that would need to be measured in order to estimate the gross productivity of an animal population in $g\,m^{-2}\,yr^{-1}$. [2]

Changes

<div style="text-align:right">Revised ☐</div>

Limiting factors and carrying capacity

<div style="text-align:right">Revised ☐</div>

Limiting factors restrict the growth of a population or prevent it from increasing further.

■ Limiting factors in plants include light, nutrients, water, carbon dioxide and temperature.
■ Limiting factors in animals include space, food, mates, nesting sites and water.

When a graph of population growth is plotted against time, an **S-population curve** is generally produced (Figure 2.27).
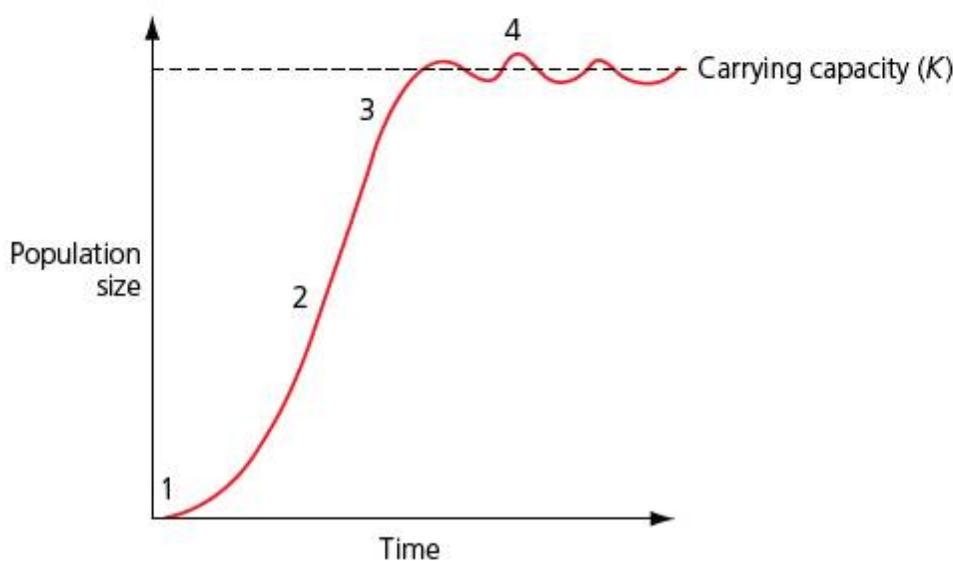
Figure 2.27 Population growth curve controlled by limiting factors

■ There is slow initial growth when the population is small (point 1 in Figure 2.27).
■ With low or reduced limiting factors the population expands **exponentially** into the habitat (point 2, Figure 2.27).
■ As a population grows then there will be increased competition between the individuals of that population for the same limiting factors, i.e. resources.
■ This results in a lower rate of population increase (point 3, Figure 2.27).
■ Population reaches its **carrying capacity**, fluctuating around a set point determined by the **limiting factors** (point 4, Figure 2.27).
■ Changes in limiting factors cause the population size to increase and decrease.
■ Increases and decreases around the carrying capacity are controlled by **negative feedback** mechanisms.

> **Key word definition**
> **Carrying capacity** is the maximum number of a species or 'load' that can be sustainably supported by a given environment.

■ **QUICK CHECK QUESTIONS**

30 Define the term *carrying capacity*.
31 Explain why populations fluctuate around a set point.

S- and J-population curves

S-population curve

Figure 2.27 shows an **S-population curve**. The curve shows the establishment of a population following introduction into a new environment. There are four stages:
- **Lag phase**, where population numbers are low leading to low birth rates (point 1, Figure 2.27).
- **Exponential growth stage**, where limiting factors are not restricting the growth of a population (point 2, Figure 2.27).
- **Transitional phase**, as limiting factors begin to affect the population and restrict its growth (point 3, Figure 2.27).
- **Plateau phase**, where limiting factors restrict the population to its carrying capacity (point 4, Figure 2.27). Changes in limiting factors, predation, disease and abiotic factors cause populations to increase and decrease around the carrying capacity (K).

J-population curves

J-population curves show only exponential growth. Growth is initially slow but becomes increasingly rapid, and does not slow down as population increases (see Figure 2.28).
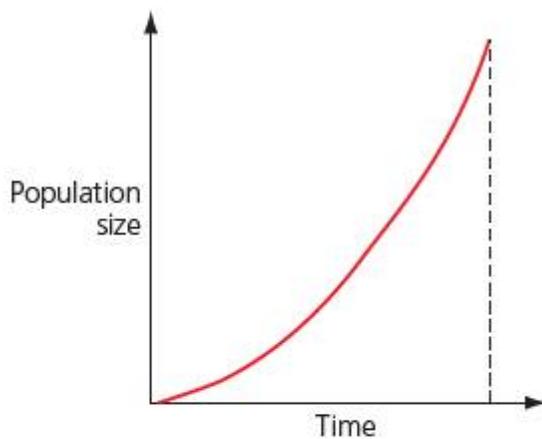
Figure 2.28 J-population growth curve

- The population is not controlled by limiting factors in the exponential growth phase.
- After reaching its peak value, the population will suddenly decrease (dotted line on Figure 2.28).

Populations showing J-shaped curves are controlled by abiotic but not biotic factors. Abiotic factors cause the sudden decrease in the population (the **population crash**).

■ **QUICK CHECK QUESTIONS**
32 Outline the stages of an S-population growth curve.
33 Explain the differences between S- and J-population growth curves.

Density-dependent and density-independent factors

- **Density-dependent factors** are limiting factors that are related to population density. They are biotic factors (e.g. competition for resources) that limit population growth.
  - □ **Internal** density-dependent factors might include fertility or size of breeding territory
  - □ **External** density-dependent factors might include predation or disease.
- **Density-independent factors** are abiotic and do not depend on the size of the population.

Density-dependent factors operate as negative feedback mechanisms leading to stability or regulation of the population.

Key word definition
K-strategists are species that usually concentrate their reproductive investment in a small number of offspring, thus increasing their survival rate and adapting them for living in long-term climax communities.

When the population growth of a species is determined by limiting factors it reaches a carrying capacity, *K*. Populations of these **K-selected species**, or **K-strategists**, are controlled by **density-dependent** factors. Examples include elephants, humans and whales.

Other species have high reproductive (*r*) rates and are known as **r-selected species** or **r-strategists**. They are controlled by **density-independent** factors. Examples include house flies, cockroaches and mosquitoes.

> **Key word definition**
> **r-strategists** are species that tend to spread their reproductive investment among a large number of offspring so that they are well adapted to colonise new habitats rapidly and make opportunistic use of short-lived resources.

Table 2.8 Comparison of *r*- and *K*-strategist species

r-strategist	*K*-strategist
Smaller in size	Larger in size
Early maturity and reproduction	Late maturity and delayed reproduction
Little or no parental care	Large amount of parental care
Large number of offspring	Few offspring
Little investment in individual offspring	High investment in individual offspring
Rapid growth and development	Slow development
Shorter life	Longer life
Thrive in unstable environments	Thrive in stable environments
J-population growth curve	S-population growth curve
Generalist species	Specialist species

Survivorship curves

Revised

Survivorship curves plot the number of offspring surviving in a population over time. They show changes in survivorship over the lifespan of the species. Time is shown as percentage of the total lifespan (*x*-axis). The *y*-axis (number of survivors) is shown as a **logarithmic scale** (i.e. increase is not linear but 1, 10, 100, etc.). This allows very large values to be shown on the same graph as very small values.

Factors that affect survivorship include:
- competition for resources
- predator–prey relationships
- amount of parental care.

Survivorship curves for *r*-selected species show most individuals dying at a young age but those that survive are likely to survive for a long time (Figure 2.29).
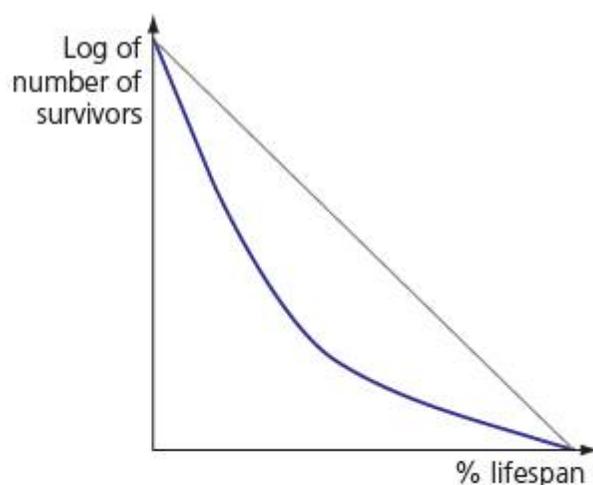
Figure 2.29 Survivorship curve for *r*-selected species

Survivorship curves for *K*-selected species show almost all individuals surviving for their potential life span, and then dying almost simultaneously (Figure 2.30).
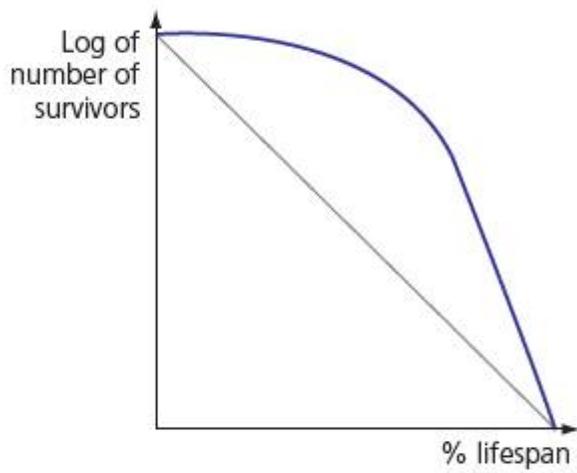
Figure 2.30 Survivorship curve for *K*-selected species

Many species lie between the extremes shown by *r*- and *K*-strategist species, and are known as *C*-strategists or *C*-selected species. These are shown by the straight lines in Figures 2.29 and 2.30.

■ **QUICK CHECK QUESTIONS**

34 Outline the differences between *r*-strategist and *K*-strategist species.
35 Sketch the survivorship curves for *r*-strategist and *K*-strategist species.

Succession and zonation

Succession

Key word definition
Succession is the orderly process of change *over time* in a community. Changes in the community of organisms frequently cause changes in the physical environment that allow another community to become established and replace the former through competition. Often, but not inevitably, the later communities in such a sequence or **sere** are more complex than those that appear earlier.

Key word definition
A **sere** is the set of communities that succeed one another over the course of succession at a given location.

Key word definition
A **climax community** is a community of organisms that is more or less stable, and that is in equilibrium with natural environmental conditions such as climate. It is the end point of ecological succession.
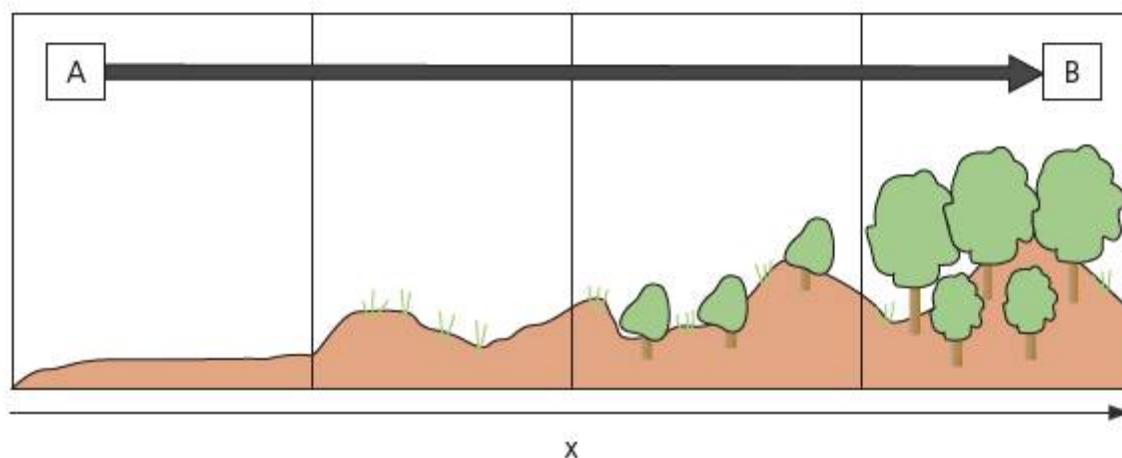
Figure 2.31 Succession in a sand dune ecosystem. The *x*-axis represents either time or distance from the sea. **A** is a **pioneer community** and **B** a **climax community**

Table 2.9 Comparison of pioneer and climax communities

Pioneer communities	Climax communities
Contain the first organisms to colonise a new environment	The end-point of ecological succession
Dominated by *r*-strategists	Dominated by *K*-strategists
Simple in structure with low diversity	Complex in structure with high diversity
Tolerate harsh conditions, e.g. strong light/low nutrient levels	Characteristics determined by climate and soil
Example: community of lichens covering bare rock	Example: mature rainforest ecosystem

Examples of succession, from pioneer community to climax community, are shown in Figures 2.32 and 2.33.

aquatic plants (e.g. water lilies) → reeds → low woodland species (e.g.willow)

Figure 2.32 Succession in freshwater

mosses and lichens → grasses and herbs → shrubs (e.g. birch) → woodland

Figure 2.33 Succession in an abandoned quarry

Zonation
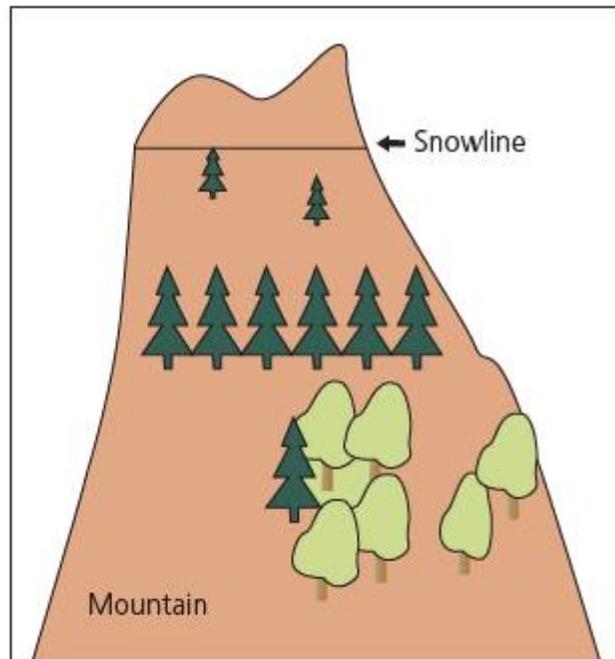
Figure 2.34 Zonation of vegetation on a mountain

Key word definition
Zonation is the arrangement or patterning of plant communities or ecosystems into parallel or sub-parallel bands in response to change, *over a distance*, in some environmental factor. The main biomes display zonation in relation to latitude and climate. Plant communities can also display zonation with altitude on a mountain, or around the edge of a pond in relation to soil moisture.

CASE STUDY

MOUNT KINABALU, BORNEO
Mount Kinabalu in Malaysian north Borneo is an example of altitudinal zonation where plant communities vary from tropical rainforest at low levels to alpine communities near the summit. Zonation is caused by changes in temperature, from 26°C in the rainforest zone to 0°C at the summit.

Figure 2.35 Mount Kinabalu: an example of altitudinal zonation

Expert tips
The concept of succession, occurring *over time*, should be carefully distinguished from the concept of zonation, which refers to a *spatial pattern*. An exam question may ask you to distinguish between the two.

If you are asked to give an example of a succession, include organisms from a pioneer community, the climax community and the seral stages in between.

■ QUICK CHECK QUESTIONS
36 Define the term *succession*.
37 Distinguish between the terms *succession* and *zonation*.
38 Define the term *climax community*.
39 Outline the differences between pioneer and climax communities.
40 Give an example of a succession. How would this succession change over time?

Changes through a succession

Table 2.10 shows the changes that occur though a succession, from point A through to B in Figure 2.31 (page 30).

Table 2.10 Features of an ecosystem at early and late stages during the process of succession

	Pioneer community	Climax community
Amount of organic matter	Small	Large
Soil depth	Shallow	Deep
Soil quality	Immature/little organic material	Mature/much organic matter
Nutrients	External	Internal
Nutrient cycles	Open system	Closed system
Nutrient conservation	Poor	Good
Role of detritus	Small	Large
Stability	Poor	Good
Niches	Wide	Narrow
Species richness	Low	High
Diversity	Low	High
Size of organisms	Small	Large
Life cycles	Simple	Complex
Growth form	*r*-selected species	*K*-selected species

Productivity also changes through a succession:
- In *pioneer communities*, gross productivity is low due to the initial conditions and the low density of producers. The proportion of energy lost through community respiration is also relatively low. Net productivity is therefore high: the system grows and biomass accumulates.
- In *later stages* there is an increased consumer community.
- In *climax communities* gross productivity may be high, but this is balanced by respiration. The **production:respiration (P:R) ratio** is a measure of productivity relative to respiration. Net productivity approaches 0 and the P:R ratio approaches 1.

> **Common mistake**
>
> It is not enough to say that 'productivity increases through a succession'. GPP increases but NPP decreases as community respiration increases.

Climax communities

Climatic and edaphic (soil) factors determine the nature of a climax community. Climax communities are more stable than earlier seral stages because:
- they contain more complex food webs – this provides more stability because if one organism goes extinct it can be replaced by another
- negative feedback mechanisms lead to steady-state equilibrium
- each seral stage helps to create a deeper and more nutrient-rich soil, so allowing larger plants to grow
- a climax community is more productive, providing more energy to support consumers and decomposers
- increased biomass leads to an increased number of niches, which increases species and genetic diversity, resulting in greater stability.

Human factors frequently affect this process through, for example burning, agriculture, deforestation, hunting, grazing and habitat clearance. Disturbance stops the process of succession so that the climax community is not reached. Interrupted succession is known as a **plagioclimax**. Human activity can have various effects on climax communities:
- Decrease in productivity through the removal of primary producers.

- Reduction in producers, leading to reduced habitat diversity and fewer niches, which threatens more specialised species.
- Deterioration in abiotic factors, leading to harsher conditions that fewer species can adapt to.
- Species extinction, leading to shorter food webs.
- A less complex community, leading to decreased stability.

Figure 2.36 Interrupting a succession through human activity

EXAM PRACTICE

15 Compare the strategies that pioneer species and climax community species are likely to have in terms of specific growth rate, parental care and competitive advantage.   [4]

16 Explain what is meant by the terms *ecological succession, pioneer community* and *climax community*.   [6]

17 Describe and explain how gross primary productivity changes during the stages of succession.   [6]

18 Distinguish between the terms *succession* and *zonation*.   [6]

Measuring changes in the system

Revised ☐

Measuring changes along an environmental gradient

Revised ☐

Ecological gradients are found where two ecosystems meet or where an ecosystem ends. Abiotic and biotic factors change along an ecological gradient (see pages 14–16 for a review of sampling techniques).

Transects are used to measure changes along the gradient, which ensures that all parts of the gradient are measured (Figure 2.37):
- The whole transect can be sampled – a **continuous** transect – *or* samples can be taken at points of equal distance along the transect – an **interrupted** transect.

- A **line transect** is the simplest transect, where a tape measure is laid out in the direction of the gradient. All organisms touching the tape are recorded.
- A **belt transect** allows more samples to be taken – a band usually between 0.5 m and 1 m is sampled along the gradient.

Figure 2.37 Sampling along an environmental gradient on a shingle ridge succession. A tape measure is laid out at 90° to the sea and abiotic and biotic factors measured at regular intervals along it

Quadrats can be used to sample at regular intervals along a transect (see page 16 for further information):
- **Frame quadrats** are empty frames of known area (e.g. 1 m²).
- **Grid quadrats** are frames divided into 100 small squares.
- **Point quadrats** are made from a frame with 10 holes, inserted into the ground by a leg (see Figure 2.38). They are used for sampling vegetation that grows in layers. A pin is dropped through each hole in turn and the species touched are recorded. The total number of pins touching each species is converted to percentage frequency data (i.e. if a species touched 7 out of the 10 pins it has 70% frequency).

Zonation can be measured by recording biotic and abiotic factors at fixed heights along a transect:
- A cross staff is used to move a set distance (e.g. 0.6 m) vertically up the transect (Figure 2.39).
- The staff is set vertically and a point measured horizontally from an eye-sight 0.6 m from the base of the staff.
- Biotic and abiotic factors are measured at each height interval.

Expert tip

Studying both biotic and abiotic factors allows research questions such as *how do abiotic factors affect the distribution of organisms in ecosystems?* Different species can be expected to be found at different locations along the gradient as they will be adapted to different conditions.

Common mistake

Do not confuse the terms biotic and abiotic – biotic refers to the living parts of the ecosystem and abiotic to the non-living parts.

Figure 2.38 A point quadrat being used to measure.

Figure 2.39 A cross staff being used to relocate quadrats at regular height intervals along a rocky shore. This allows zonation on the shore to be studied.

■ **QUICK CHECK QUESTIONS**
41 What is meant by the term *ecological gradient*.
42 Outline how you would measure changes in abiotic factors along an environmental gradient.
43 Describe three different methods for recording biotic factors along a belt transect.
44 Describe how you would collect data to show zonation in an ecosystem.

Measuring changes due to a specific human activity

Human activities can change abiotic and biotic components of an ecosystem. Human impacts include toxins from mining activity, landfills, eutrophication, effluent, oil spills and overexploitation.

CASE STUDY

DEFORESTATION IN THE AMAZON

Scientists are measuring the effects of human activity on the Amazon rainforest.

- Logging is causing large areas of forest to be lost.
- Deforestation is being carried out to provide timber, and to clear land for agriculture and housing.
- Remaining areas can become fragmented, forming islands of habitat.

Satellite photos can be used to monitor the amount of deforestation taking place.

- This method is very reliable, can cover a large area, and monitors change over time.
- The visual impact of the photos is useful for motivating action against logging.

Figure 2.40 Satellite photo showing deforestation in the Amazon rainforest

Abiotic and biotic factors can be measured:

- These must be taken in both undisturbed and disturbed habitats so that comparisons can be made.
- Habitat islands of different sizes will have different environmental conditions, and so a variety of different-sized patches must be measured.
- Samples must be repeated so that data are reliable.
- Abiotic factors can include temperature, humidity and sunlight.
- Biotic factors can include the species of plants and animals present, and the population size of selected indicator species.
- Where environmental gradients are present, factors must be measured along the full extent of the gradient so that valid comparisons can be made.
- Factors must be measured over a long period of time to take into account daily and seasonal variations.
- See pages 14–16 for description and evaluation of methods for measuring abiotic and biotic factors.

Environmental impact assessments

> **Key word definition**
> An **environmental impact assessment** (EIA) is a method of detailed survey required, in many countries, before a major development. Ideally it should be independent of, but paid for by, the developer. It should include a baseline study, and monitoring should continue after completion of project.

An EIA is carried out before a development project or large change in the way an area of land is used. It includes a **baseline study** to measure environmental conditions before development commences, and to identify areas and species of conservation importance. The baseline study is used to try to forecast what changes might be caused by the development and includes measurement of abiotic components, biodiversity, aesthetic aspects (e.g. scenery) and human populations in the area. It identifies possible impacts, predicts the scale of potential impacts and finds ways to lower the impacts.

The resulting report is known as an **environmental impact statement** (EIS) or environmental management review in some countries. A **non-technical summary** is also produced so that the general public can understand the issues.

Development projects include: road construction, hydroelectric power plants, river dams, airports, new housing, mines and brown field development. Monitoring should continue for some time after the development. The purpose of an EIA is to weigh the advantages and disadvantages of the proposed development before the project proceeds.

- This aids in the planning of the development.
- It helps to understand the environmental impact that a project might have before it is put into place
- It helps to determine ways to minimise the damage done to the environment.
- It helps to support the goal of sustainable development.
- It investigates economic benefits and other positive impacts of the project.

CASE STUDY

LONDON 2012

An EIA was carried out to assess the impacts of the London 2012 Olympics on the area of east London where the Olympic Park was to be built. The EIA was structured to address the environmental effects resulting from development of the Olympic Park. It was divided into four phases:

- Olympic and Paralympic Construction, 2007–2011
- The period during the Olympic and Paralympic Games, 2012
- Olympic Legacy Transformation, 2013–2014
- Olympic Legacy, 2015–2021.

The environmental effects were assessed for each of these phases against a baseline, which represented the conditions on the site if the London 2012 Games had not taken place.

The EIA identified the likely impacts of the development and proposed measures to reduce or offset adverse effects (mitigation measures). For example, during the construction phase, it was predicted that construction traffic would affect the flow of traffic, air quality, noise levels and the general character of the area around the site.

It was proposed that these problems would be reduced by limiting and controlling times when construction traffic was active, using a waste management strategy that limited the amount of waste being transported, and using local waterways to move material on and off the site.

A seven-point scale was used to assess the environmental impacts (Table 2.11):

1 = major adverse

2 = moderate adverse

3 = minor adverse

4 = neutral

5 = minor beneficial

6 = moderate beneficial

7 = major beneficial.

Conclusions about environmental impacts assumed that proposed mitigation measures had been put into place.

Table 2.11 The overall assessments of environmental effects, using the seven-point scale

ENVIRONMENTAL IMPACT	ASSESSMENT PERIOD			
	2007–2011	2012	2013–2014	2015–2021
Traffic and transport: highways public transport walking and cycling	3 2/3 4/5	2 3/4 2/3	4 5/6 6	4/5 4/5 7
Energy: energy infrastructure energy demand carbon emissions heat island effect	3 4 4 4	4 4 4 4	6 4 4 5	5 4 4 5
Socio-economic and community: employment sport and leisure retail culture health	6 4 5 6 5	6/7 7 5 7 6	6 6 5 7 6	6 7 5 7 6
Visual effects	2	6	2	6
Soil conditions, groundwater, contamination	7	4	3	4
Water: water quality aquatic ecology hydrology flood risk	3 3 2 4	4 6 3 4	3 6 3 4	5 6 3 4
Terrestrial ecology and nature conservation	3	3	3	5
Air quality	4	4	4	4

Overall, by the final stage of the development, all environmental effects were predicted to be neutral or better, with major benefits for walking and cycling, sport, leisure and culture.

In May 2009, the Olympic Board stated that London 2012 had a clear policy for alleviating the impacts of manufacture, supply, use and disposal of material for the 2012 Olympic Games. The design of the Olympic Park therefore ensured that the environmental impacts were minimised.

■ **QUICK CHECK QUESTIONS**

45 Outline how human activities can change the abiotic and biotic components of an ecosystem.
46 Describe and evaluate methods for measuring changes in abiotic and biotic components of an ecosystem due to a **named** specific human activity.
47 Describe the stages of an environmental impact assessment.
48 Describe and evaluate the use of environmental impact assessments.

EXAM PRACTICE

19 a Describe how changes in species composition along an environmental gradient might affect a **named** abiotic factor. [2]

b Outline and evaluate methods, which you could use in the field, to gather evidence for **i)** species composition and **ii)** your suggestion in a. [6]

20 Describe a method for measuring changes in abiotic components in a **named** ecosystem affected by human activity. [5]

21 a Suggest **two** characteristics of species that usually make them suitable for sampling with quadrats. [2]

b Explain how you might ensure that the quadrats were placed at random. [2]

22 a Define the term *environmental impact assessment*. [2]

b When a new airport is proposed, an environmental impact assessment (EIA) will be commissioned. Describe the stages of an EIA. [3]

Population dynamics

The nature and implications of exponential growth in human populations

- The world's population has grown rapidly or **exponentially**. Most of this growth is quite recent and much of it has been in south and east Asia.
- Rapid growth is likely to take place until at least 2050. Global population doubled between 1650 and 1850, 1850 and 1920, and 1920 and 1970. It is thus taking less time for the population to double.
- Up to 95% of population growth is taking place in less economically developed countries (LEDCs). However, the world's population is expected to stabilise at about 12 billion by around 2050–80.

Figure 3.1 shows that in most regions population change increased between 1930 and 1960, and again between 1960 and 1990. The exceptions were North America and Europe. In contrast, the projected changes for 1990–2020 show that population growth rates will fall in all regions, notably South America, Asia and Australasia.

Population growth can lead to:
- great pressures on governments to provide for their people
- increased pressure on the environment
- increased risk of famine and malnutrition
- greater differences between the richer countries and the poorer countries.

> **Key word definition**
> **Exponential growth** is an increasing or accelerating rate of growth, sometimes referred to as a J-shaped or J-population curve.

> **Expert tip**
> If you can refer to particular dates and population sizes – for example, the world's population reached 7 billion in 2011 – that will gain you extra credit.

> **Common mistake**
> The world's population is not currently undergoing exponential growth – it is slowing down – more of an S-population curve than a J-population curve.
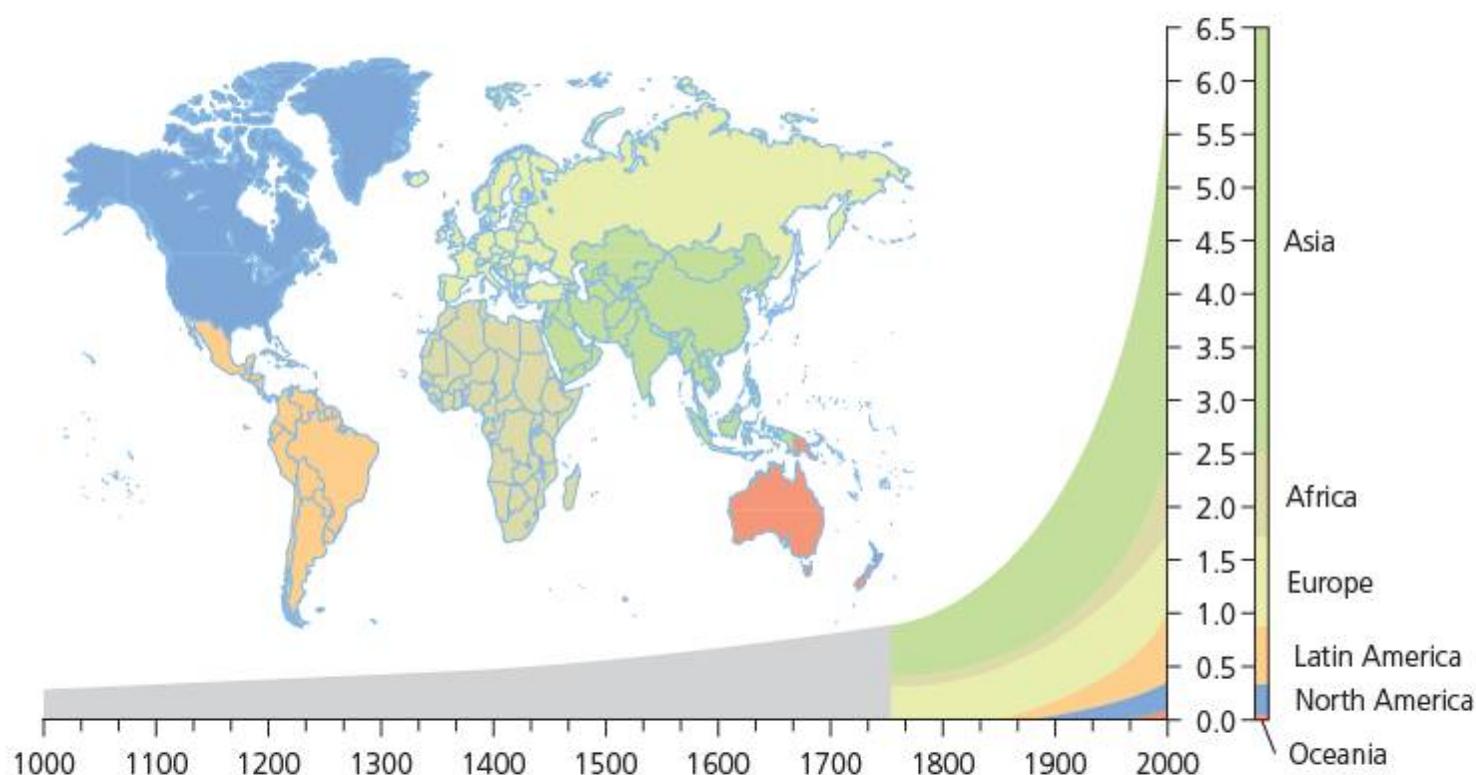

Figure 3.1 Exponential growth of the world's population, 1750–2050

Birth rate, crude death rate, fertility, doubling time and natural increase rate

Natural increase or the **annual growth rate** is found by subtracting the crude death rate (‰ – per thousand) from the crude birth rate (‰) and is then expressed as a percentage (%):

$$\text{natural increase (\%)} = \frac{\text{birth rates per 1000} - \text{death rates per 1000}}{10}$$

Highest growth rates are found in Africa, while lowest growth rates are in North America and Europe.

Doubling time is the length of time it takes for a population to double in size, assuming its natural growth rate remains constant. Approximate values for it can be obtained by using the formula:

$$\text{doubling time (years)} = \frac{70}{\text{growth rate in percentage}}$$

Life expectancy (E_0) is the average number of years that a person can be expected to live, usually from birth, if demographic factors remain unchanged.

> **Key word definitions**
>
> **Crude birth rate** (CBR) is the number of live births per 1000 people in a population.
>
> **Total fertility rate** (TFR) is the average number of births per 1000 women of childbearing age.
>
> **Crude death rate** (CDR) is the number of deaths per 1000 people in a population.
>
> **Infant mortality rate** (IMR) is the number of deaths of children less than 1 year old per 1000 live births.

Table 3.1 Selected population indicators

	UK	China	Brazil	Ethiopia
CBR (‰)	12.27	12.31	17.48	42.59
TFR (‰)	1.91	1.55	2.16	5.97
CDR (‰)	9.33	7.17	6.38	10.79
IMR (‰)	4.56	15.62	20.50	75.29
Life expectancy (years)	80.17	74.84	72.79	56.56
Growth rate (%)	0.29	0.51	1.11	3.18
Doubling time (years)	241	137	64	22

> **Expert tip**
>
> When describing a map of global variations in birth rates or fertility rates, look out for the highest, lowest, trends and exceptions. Also, make sure you use the key, and give some examples of each.

> **Common mistake**
>
> Crude birth rates and crude death rates are called crude because they do not take into account the age structure of a population.

Factors affecting birth rates and fertility rates

Changes in birth rates and fertility rates are a combination of both **socio-cultural** and **economic** factors:

- In countries where the **status of women** is low and few women are educated or have paid employment, birth rates are high.
- In countries, such as Singapore, where the status of women has improved, the birth rate has fallen.
- In general, the higher the level of parental **education**, the fewer the children. The high cost of children in a wealthy society helps to explain the falling birth rates in rich countries.
- The role of **religion** in relation to fertility rates is commonly confused. In general, most religions are pro-natalist, i.e. they favour large families.
- **Economic prosperity** favours an increase in the birth rate, while increasing costs lead to a decline in the birth rate.
- High infant mortality rates increase the pressure on women to have more children. Such births are termed **replacement births** or **compensatory births** to offset the high mortality losses.
- In some agricultural societies, parents have larger families to provide labour for the farm and as security for the parents in old age.

Patterns of mortality

- At the global scale, the pattern of mortality in rich countries differs from that in poor countries.
- In rich countries, as a result of better **nutrition, health care** and **environmental conditions (housing, safe water, proper sanitation)**, the death rate has fallen steadily, with very high life expectancies (75+years).
- In many of the very poor countries, high death rates and low life expectancies are still common, although both have shown steady improvement over the past few decades. This trend, unfortunately, has been reversed as a consequence of AIDS in some parts of the world, especially sub-Saharan Africa and Russia.
- Some populations, such as those in retirement towns and especially in the older industrialised countries, have very high life expectancies and this in turn results in a rise in the CDR. Countries with a large proportion of young people will have much lower death rates.

■ QUICK CHECK QUESTIONS

1 Approximately what was the world population in a) 2000 and b) 2010?
2 From the data provided in the table below, state the natural increase and the doubling time for Afghanistan and the USA.

	Afghanistan	USA
Birth rate (‰)	39.30	13.68
Death rate (‰)	14.59	8.39
Natural increase (%)		
Doubling time (years)		

Age-sex (population) pyramids

Revised

Population structure or composition refers to any *measurable* characteristic of the population. This includes the age, sex, ethnicity, language, religion and occupation of the population. Population pyramids tell us a lot of information about the age and sex structure of a population:

- A wide base suggests a high birth rate.
- A narrowing base indicates a falling birth rate.
- Straight or near vertical sides shows a low death rate.
- A concave slope suggests a high death rate.
- Bulges in the slope indicate high rates of in-migration (for instance, excess elderly, usually female, will indicate retirement resorts; excess males aged 20–35 years will be economic migrants looking for work).
- Deficits in the slope show out-migration or age-specific or sex-specific deaths (war, epidemics).

Population pyramids (see Figure 3.2) are important because they tell us about population growth. They help planners to find out how many services and facilities, such as schools and hospitals, will be needed in the future.

Key word definition
Age-sex pyramids are bar graphs that show the relative or absolute amount of people in a population at different ages and of different sexes.

Germany: 2000

MALE | FEMALE

Knock-on effect of large cohort

Very high death rate in over 80 yr old men due to Second World War

High birth rate in expansionist Germany (pre war)

Low birth rates after war due to high male mortality in war

Large decline in birth rate

100+ 95–99 90–94 85–89 80–84 75–79 70–74 65–69 60–64 55–59 50–54 45–49 40–44 35–39 30–34 25–29 20–24 15–19 10–14 5–9 0–4

4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0

Germany: 2050

MALE | FEMALE

Increasingly elderly population

Steep sides indicates low death rate

Large imbalance between female and male especially over 85 yrs

Declining birth rate

100+ 95–99 90–94 85–89 80–84 75–79 70–74 65–69 60–64 55–59 50–54 45–49 40–44 35–39 30–34 25–29 20–24 15–19 10–14 5–9 0–4

4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
Population (in millions)

Figure 3.2 Population pyramids for Germany, 2000 and 2050

The demographic transition model

The **demographic transition model** (DTM) describes how birth rates and death rates change over time. It was developed from a study of changes in birth rates and death rates in England and Wales, and in Sweden.

The DTM is usually divided into four stages and, increasingly, a fifth stage (Figure 3.3). It is a useful diagram as it displays visually the complex patterns of change in birth rate, death rate, natural increase (i.e. the increase brought about when birth rates exceed death rates), natural decrease (the decrease in population when death rates exceed birth rates) and population growth rates.

Key word definition
The **demographic transition model** is a model that shows the change in a population from one that has high birth rates and high death rates to a country that has low birth rates and low death rates.

| Stages | 1 High stationary | 2 Early expanding | 3 Late expanding | 4 Low stationary | 5 Natural decrease |

Births and deaths per 1000 per year

40
30
20
10
0

Birth rate

Death rate

Population growth

Time
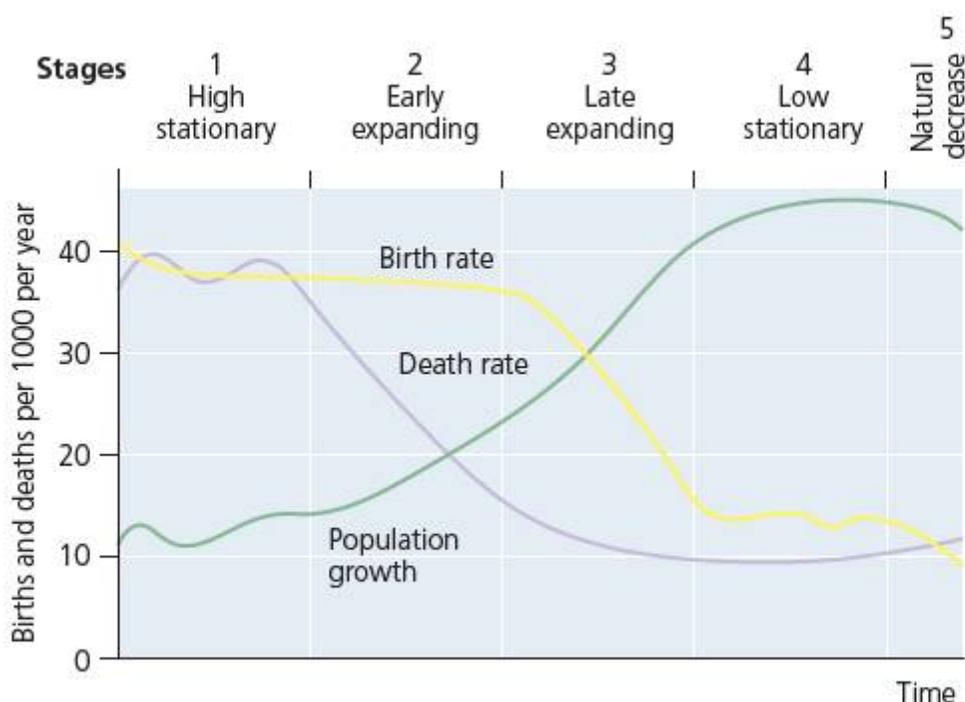
Figure 3.3 Typically five stages are identified in the demographic transition model

■ **QUICK CHECK QUESTION**

3   Describe the main characteristics of the age-sex pyramid shown below.
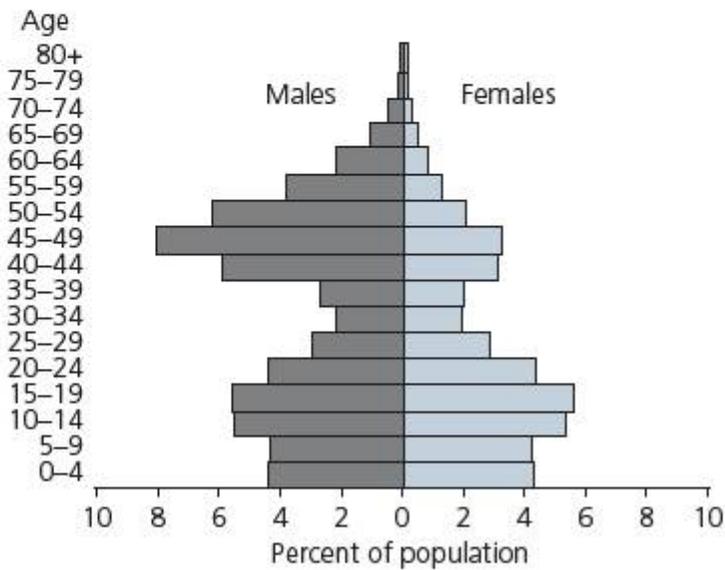
The use of models in predicting the growth of human populations

Revised ☐

- Computer models can be used to predict future population growth. However, there are usually high-, medium- and low-growth scenarios.
- The further into the future we try to predict, the less accurate predictions become.
- Demographic and statistical tables can be produced. The World Bank provided the data for South Africa and Ethiopia in Table 3.2.
- Age-sex pyramids can also be used to predict demographic change (Figure 3.2 on page 42 and Figure 3.4 on page 44).

Table 3.2 Demographic and economic data for South Africa and Ethiopia

2010	South Africa	Ethiopia
Population, total (millions)	50.0	83.0
Population growth (annual %)	1.4	2.1
GDP (current US$, billions)	363.9	29.7
GDP per capita (current US$)	7280	358
GDP growth (annual %)	2.8	10.1
Life expectancy at birth, total (years)	52.1	58.7
Mortality rate, infant (per 1000 live births)	40.7	67.8
Literacy rate, youth female (% of females aged 15–24)	98.1	33.3

Source: World Development Indicators

Botswana: 2000

MALE · FEMALE

High proportion of young <20 yrs

Low proportion of over 60 yr olds

Very high death rates – impact of AIDS

High birth rates in previous generations

Slowing birth rate

Falling birth rate

100+
95–99
90–94
85–89
80–84
75–79
70–74
65–69
60–64
55–59
50–54
45–49
40–44
35–39
30–34
25–29
20–24
15–19
10–14
5–9
0–4

120 100 80 60 40 20 0   0 20 40 60 80 100 120

Botswana: 2050

MALE · FEMALE

High death rates

Death rates low

Small proportion of elderly (>60 yrs) through death rates

High death rates: AIDS

Declining birth rate

100+
95–99
90–94
85–89
80–84
75–79
70–74
65–69
60–64
55–59
50–54
45–49
40–44
35–39
30–34
25–29
20–24
15–19
10–14
5–9
0–4

120 100 80 60 40 20 0   0 20 40 60 80 100 120

Population (in thousands)

Figure 3.4 Population pyramids for Botswana, 2000 and 2050

EXAM PRACTICE

1 Describe the population growth in Europe, as shown in Figure 3.1. [3]
2 Explain the implications of exponential growth in human populations. [4]
3 Examine how socio-cultural and economic factors affect birth rates. [8]
4 Analyse the demographic transition model as a way of showing population change. [6]
5 How do the data in Table 3.2 help predict the growth of population in South Africa and Ethiopia? [6]
6 a Study the population pyramid for Haiti in 2010. Describe, giving a reason, how Haiti's population is likely to change over the next 20 years. [2]

Haiti: 2010

MALE · FEMALE

80+
75–79
70–74
65–69
60–64
55–59
50–54
45–49
40–44
35–39
30–34
25–29
20–24
15–19
10–14
5–9
0–4

700 600 500 400 300 200 100 0   0 100 200 300 400 500 600 700

Population (in thousands)
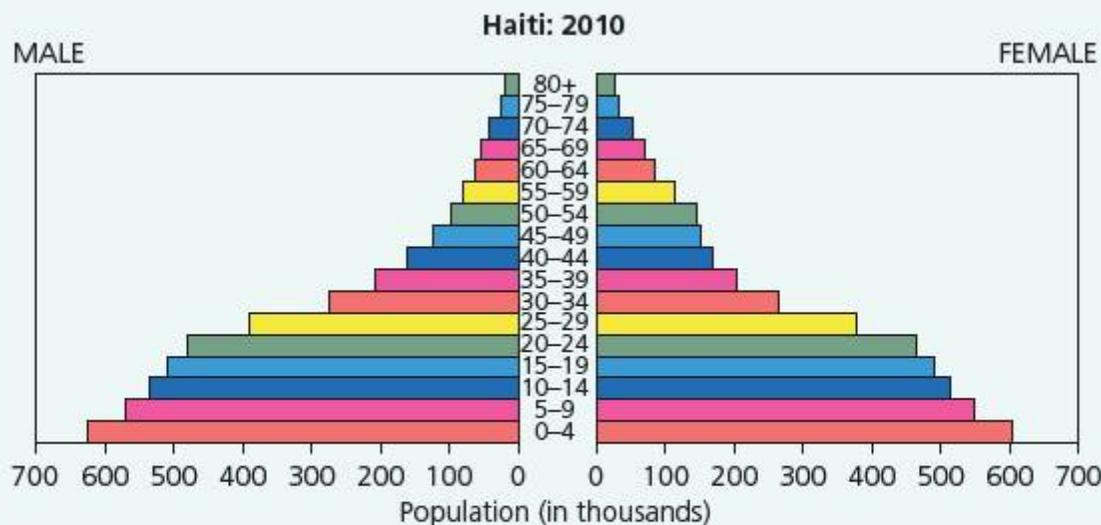
  b Suggest reasons why Haiti's population might not expand rapidly over the next 20 years. [3]

Resources: natural capital

Resources and natural income

- Resources are everything that is useful to mankind.
- They include air, water, soil, people, education, fossil fuels, ecosystems and so on.
- People can get many benefits from resources.
- Some environmentalists describe resources as 'natural capital'.
- They often make a comparison with saving money (capital) in a bank. At the end of the year, the savings (capital) may have gained some interest.
- Likewise, with natural resources (**natural capital**), over time these may produce more resources, and so people can live off the 'interest' – this is known as '**natural income**'.
- Both renewable and replenishable resources can produce natural income indefinitely in the form of valuable goods and services.
- These goods and services include marketable goods such as timber and food or may be in the form of ecological services such as the flood and erosion protection provided by forests (services) and climate regulation.
- Some of these services are impossible to quantify.
- Non-renewable resources, such as oil and coal, generate wealth but can be used only once in a human lifetime.

> **Key word definitions**
> **Natural capital** refers to natural resources that are managed to provide goods and services for societies.
>
> **Natural income** is the portion of natural capital (resources) that is produced as 'interest', i.e. the sustainable income produced by natural capital.

> **Common mistake**
> Oil, gas and coal may be formed again in the future, but the rate of formation is so slow that they must be considered as non-renewable resources.

Ecosystem services

There are four main types of ecosystem service:

- **Supporting services** are the essentials for life and include primary productivity, soil formation and the cycling of nutrients.
- **Regulating services** are a diverse set of services and include pollination, regulation of pests and diseases and production of goods such as food, fibres and wood. Other services include climate and hazard regulation and water quality regulation.
- **Provisioning services** are the services people obtain from ecosystems such as food, fibre, fuel (peat, wood and non-woody biomass) and water from aquifers, rivers and lakes. Goods can be from heavily managed ecosystems (intensive farms and fish farms) or from semi-natural ones (such as by hunting and fishing).
- **Cultural services** are derived from places where people's interaction with nature provides cultural goods and benefits. Open spaces – such as gardens, parks, rivers, forests, lakes, the sea-shore and wilderness areas – provide opportunity for outdoor recreation, learning, spiritual well-being and improvements to human health.

> ■ **QUICK CHECK QUESTION**
> 4   Identify two forms of natural income that might be derived from the damming of rivers.

Table 3.3 Ecosystem services

Mountains, moorlands and heaths	Woodlands
Food*	Timber*
Fibre*	Species diversity*
Fuel*	Fuelwood*
Freshwater*	Freshwater*
Climate regulation†	Climate regulation†
Flood regulation†	Flood regulation†
Wildfire regulation†	Erosion control†
Water quality regulation†	Disease and pest control†
Erosion control†	Wildfire regulation†
	Air and water quality regulation†
	Soil quality regulation†
	Noise regulation†
Recreation and tourism*	Recreation and tourism*
Aesthetic values*	Aesthetic values*
Cultural heritage*	Cultural heritage*
Spiritual values*	Employment*
Education*	Education*
Sense of place*	Sense of place*
Health benefits*	Health benefits*

Key:
Items marked * denote goods
Items marked † denote services
Items in red are considered to be from provisioning services
Items in blue are from regulating services
Items in green denote cultural services

> **Expert tip**
>
> The supporting services, including primary production and nutrient cycling, are not listed for the individual habitats as they are considered necessary for the production of all other ecosystem services.

Renewable, replenishable and non-renewable natural capital

Revised ☐

> **Key word definitions**
>
> **Renewable natural capital**, such as living species and ecosystems, is self-producing and self-maintaining and uses solar energy and photosynthesis. This natural capital can yield marketable goods such as wood, but may also provide unaccounted essential services when left in place, for example, climate regulation.
>
> **Replenishable natural capital**, such as groundwater and the ozone layer, is non-living but is also often dependent on the solar 'engine' for renewal.
>
> **Non-renewable natural capital** (except on a geological timescale), such as fossil fuels and minerals, are analogous to inventories: any use implies partial depletion of the stock.

> **Expert tip**
>
> The terms natural resources and natural capital are often substituted for each other. However, the term 'natural resources' suggests that resources are there to be used, whereas natural capital suggests something to be managed to produce an income or a return on the investment.

> **Common mistake**
>
> Some students think that nuclear energy is a renewable form of energy – it is non-renewable. It is, however, considered to be an alternative form of energy (alternative to the carbon-rich fuels such as oil, natural gas and coal). Politically, some countries have considered nuclear energy alongside renewables, such as HEP and wind energy. However, uranium will run out just as fossil fuels will.

■ **QUICK CHECK QUESTIONS**

5 Define the terms *renewable natural capital* and *replenishable natural capital*.
6 For the resources listed below, identify whether each is considered to be renewable, non-renewable *or* replenishable: groundwater; potatoes; iron ore in rocks; sheep's wool; the ozone layer; water used for the generation of HEP.

The dynamic nature of the concept of a resource

Resources change over time – they are affected by cultural, economic and technological factors. For example, in the Middle Ages oil was used to treat wounds, whereas in the twentieth and twenty-first centuries it has been used as a fuel and as an industrial raw material for the plastics and chemical fertiliser industry. Uranium only became a valuable resource in the mid-twentieth century due to the development of nuclear technology.

Shale gas

Shale rocks have recently become an important potential resource because of the shale gas (natural gas) that they contain, and many countries are trying to develop their shale gas resources.

- In the USA, shale gas has 'taken off' because of a plentiful supply of shale rock, the available technology (pipelines that had been used to carry natural gas and oil are now carrying shale gas) and the country's determination to achieve 'energy security'.
- In contrast, China, although it has large deposits of shale rocks in areas such as Sichuan province, is less likely to develop shale gas as there is a risk of triggering earthquakes, such as the one that devastated Sichuan in 2008, killing over 66 000 people.
- In the UK, there are differing reports regarding the amount of shale rock deposits and the location of the rock with best potential for shale gas. Deposits in the south of the country are less likely to be developed because of a more politicised middle class population, whereas in the north of the country, the need for employment and investment could prove more powerful than environmental considerations.

> ■ **QUICK CHECK QUESTIONS**
> 7 Explain **three** ways in which the status of large herbivores, such as red deer, as a natural resource has changed over time.
> 8 Suggest how a woodland ecosystem as a resource might change over time.

> **Expert tip**
>
> Keep up to date with major developments and news items. For example, the nuclear energy industry in a number of countries, including Japan and Germany, suffered a major setback following the tsunami and explosion at the Fukushima Daiichi nuclear power station in March 2011.

> **Common mistake**
>
> It is quite common to think of energy resources when thinking of the dynamic nature of resources. However, other resources – such as ecosystems – may change in importance over time.

The intrinsic value of the environment
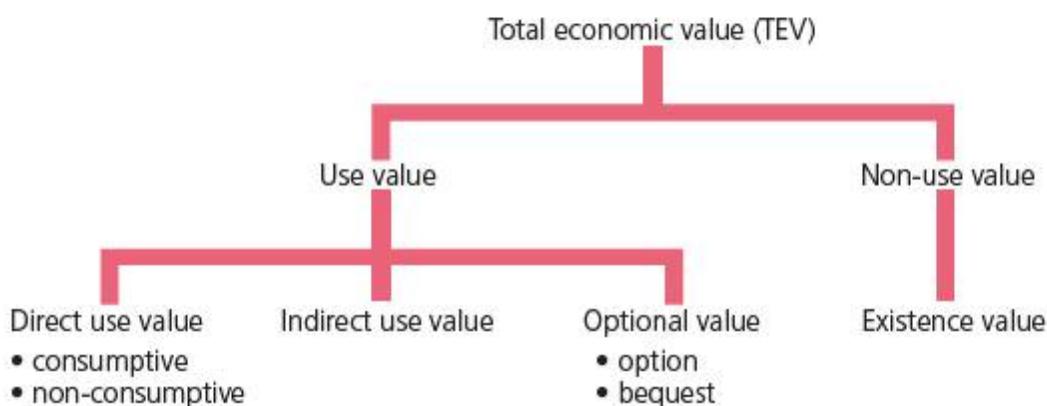
Figure 3.5 Methods of assessing natural capital

> **Key word definitions**
> **Economic value** is determined by the market price of the goods and services a resource produces.
>
> **Ecological values** have no formal market price: soil erosion control, nitrogen fixation and photosynthesis are all essential for human existence but have no direct monetary value, although some estimates have been made.

- **Direct use values** are ecosystem goods and services that are directly used by humans; most often by people visiting or residing in the ecosystem.
- **Consumptive use values** include harvesting food products, timber for fuel or housing, medicinal products and hunting animals for food and clothing.
- **Non-consumptive use values** include recreational and cultural activities that do not require harvesting of products.
- **Indirect use values** are derived from ecosystem services that provide benefits outside the ecosystem itself (e.g. natural water filtration, which may benefit people downstream).
- **Optional values** are derived from the potential future use of ecosystem goods and services not currently used – either by yourself (**option value**) or your future offspring (**bequest value**).
- **Non-use values** include aesthetic and intrinsic values, and are sometimes called **existence values**. They have no market price.

Ecosystems that are valued on aesthetic or intrinsic grounds may not provide identifiable goods or services, and so remain unpriced or undervalued from an economic viewpoint.

There are many examples of places or ecosystems that have an important national identity – for example, Mount Fuji in Japan or Mount Kilimanjaro in Tanzania. Uluru (Ayers Rock) in Australia has great spiritual value for the Aboriginal population. Such areas or ecosystems have intrinsic value from an ethical, spiritual or philosophical perspective, and are valued regardless of their potential use to humans.

There are many attempts to value nature – for example, biodiversity and rate of depletion of natural resources – so that they can be weighed more rigorously against more common economic values (for example, gross national income (GNI)). However, to a large extent these valuations are impossible to quantify realistically. Not surprisingly, much of the sustainability debate centres on the problem of how to weigh conflicting values in our treatment of natural capital.
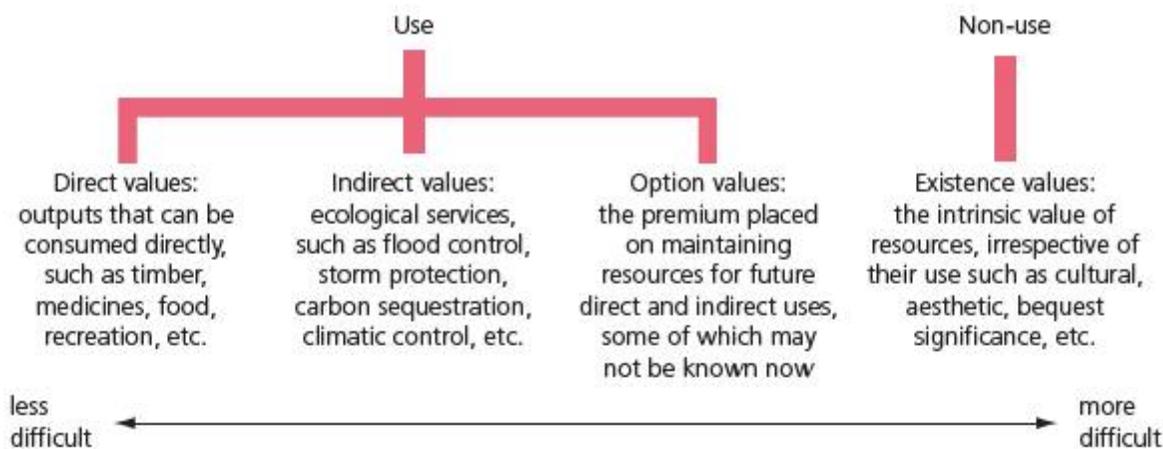
> **Common mistake**
>
> Direct and indirect values can be quantified, up to a point. However, option values and non-use values are nearly impossible to quantify – but should not be ignored.

Figure 3.6 Level of difficulty in assessing the economic value of natural capital

> **Expert tip**
>
> How can we quantify values such as aesthetic value, which are inherently qualitative? Have an example ready – such as Mount Fuji or Uluru – to support any statements that you make about the intrinsic value of nature in an examination.

> ■ **QUICK CHECK QUESTION**
>
> 9 Suggest another way of valuing the temperate deciduous woodland ecosystem other than for its economic value.

Sustainability, natural capital and natural income

Revised

- The term **sustainability** has been given a precise meaning in the *ESS Guide*. (See key word definition on right.)
- Any society that supports itself in part by depleting natural capital is unsustainable. If human well-being is dependent on the goods and services provided by certain forms of natural capital, then long-term use rates should not exceed rates of natural capital renewal.
- Sustainability means living within the means of nature, on the 'interest' or sustainable income generated by natural capital – for example, harvesting renewable resources at a rate that will be replaced by natural growth demonstrates sustainability.
- Sustainability focuses on the rate of resource use and suggests maintaining a balance between resource use and natural income.

> **Key word definition**
>
> **Sustainability** is the use of global resources at a rate that allows natural regeneration and minimises damage to the environment.

> **Expert tip**
>
> Deforestation can be used to illustrate the concept of sustainability and unsustainability.
>
> - If the rate of forest removal is less than the annual growth of the forest (i.e. the natural income), then the forest removal is sustainable.
> - If the rate of forest removal is greater than the annual growth of the forest, then the forest removal is unsustainable.

> ■ **QUICK CHECK QUESTIONS**
>
> 10 Define *sustainability*.
> 11 Explain what is meant by natural income. In what way is natural income sustainable?

Sustainable development

The term 'sustainable development' was first used and defined in 1987 in *Our Common Future* (The Brundtland Report). There are many variations on the theme of sustainable development – for example, sustainable urban development, sustainable agricultural development and sustainable economic development.

To an economist, sustainable economic development might suggest economic growth remaining consistently high whereas for an environmentalist sustainable economic development might suggest using renewable energy resources to produce environmentally friendly goods.

Some critics may argue that the evolution of sustainable development has done little to change the way in which the world works. Others may argue that we are now increasingly aware of the environmental and social consequences of human impacts at a local scale and a global scale. Being aware of the inequalities allows us to plan for a better future.

- In 1972 the **Stockholm Declaration** (the UN Conference on the Human Environment) was the first international meeting about the global environment and development.
- In 1987 the Brundtland Commission defined the term sustainable development.
- In 1992, at the **Rio de Janeiro Earth Summit, Local Agenda 21** statements were introduced. These were for all levels of government – from national to local – to help improve the environment.
- In 1997 the **Kyoto Protocol** introduced attempts to reduce emissions of CO_2.
- The 2002 **Johannesburg World Summit on Sustainable Development** focused on social issues, such as poverty, sanitation and access to water.
- In 2012 the Rio +20 conference claimed that there was a 'techno fix for every problem'. In addition, it stated that any agreements would not be legally binding.

Key word definition

Sustainable development is development that meets current needs without compromising the ability of future generations to meet their own needs.

Common mistake

Students frequently mistake *sustainability* and *sustainable development*. Remember, sustainability is the use of global resources at a rate that allows natural regeneration and minimises damage to the environment whereas sustainable development is development that meets current needs without compromising the ability of future generations to meet their own needs.

Common mistake

Many projects that societies undertake appear sustainable. Hydroelectric power (HEP) is a good example. However, a huge amount of oil and gas is used in the building of dams and transporting materials to the dam site. Moreover, the country using the dam may well use other non-renewable forms of energy in its 'energy mix'.

Table 3.4 Aspects of sustainable development

Economy	Society	Environment
- Economics of sufficiency not greed - Energy-efficient buildings - Green commuting - Reduced pollution - Reduce, reuse, recycle policies	- Cultural diversity and social stability - Lifestyle and recreational amenities - Protected common land - Education and awareness - Political action for sustainability - Sustainable built environment	- Renewable energy sources - Waste management and water treatment - Reduce, reuse, recycle policies - Protected areas and wildlife corridors

Expert tip

Learn some specific examples of sustainable schemes – for example, Curitiba (Brazil) has a sustainable transport programme and a 'green exchange' whereby residents can exchange waste products for food or bus tickets.

■ **QUICK CHECK QUESTIONS**

12 Define *sustainable development*.
13 What were the main conclusions of the Rio +20 conference?

Sustainable yield

The annual **sustainable yield** for a given crop can be estimated simply as the annual gain in biomass or energy through growth and recruitment.

Sustainable yield can be calculated from one of the following formulae:

$$\text{sustainable yield} = \text{annual growth and recruitment} - \text{annual death and emigration}$$

$$\text{sustainable yield} = \left(\frac{\text{total biomass}}{\text{energy}} \text{ at time } t+1 \right) - \left(\frac{\text{total biomass}}{\text{energy}} \text{ at time } t \right)$$

> **Key word definition**
> **Sustainable yield** (SY) can be calculated as the rate of increase in natural capital, i.e. that which can be exploited without depleting the original stock or its potential for replenishment.

> **Expert tip**
> Aquifers (water-bearing rocks) are a renewable resource that should be exploited on the basis of maximum sustainable yield. Abstraction of water should not exceed recharge, otherwise the aquifer will decline.

■ **QUICK CHECK QUESTIONS**

14 Define *sustainable yield*.

EXAM PRACTICE

7 Explain the relationship between natural income and sustainability. [3]

8 Distinguish between the terms *sustainability* and *sustainable development*. [4]

9 The diagram below shows features of sustainable development.

```
                         Sustainable development
         ┌───────────────────────┼───────────────────────┐
 Environmental              Economic                  Social
 sustainability            achievements              stability
      │              ┌───────────┴───────────┐           │
 Natural capital   Resource      Sustainable         Social cohesion
                   intensity     innovation
      │                │              │                   │
    Land             Energy        Education          Health care
    Water            Water         Innovation         Equal opportunities
    Biomass          Climate change Infrastructure    Crime
    Mineral resources Raw materials Economic policies  Freedom
```

a State the **three** main aspects of sustainable development. [3]

b Outline ways in which some of these features may be linked. [3]

Energy resources

The range of energy resources available to society

There is a range of energy resources available to societies. The most common classification is into **renewable** and **non-renewable** resources. Non-renewable resources include oil, natural gas and coal and account for the bulk of the world's energy supply. Renewable resources include hydroelectric, solar, tidal, wind, geothermal and biomass (fuelwood, dung).

Figure 3.7 shows how energy resources have changed over much of the twentieth century and how they are predicted to change up until 2050.

Energy consumption has traditionally been much higher in rich countries (more economically developed countries) than poor countries (less economically developed countries). This is because rich countries have more energy sources and economies that are based on energy-intensive industries.

As poor countries industrialise (newly industrialising countries – NICs – such as China and India), they are using vastly more energy that they did a few decades ago.

> **Key word definition**
> **Non-renewable** refers to natural resources that cannot be replenished within a timescale of the same order as that at which they are taken from the environment and used – for example, fossil fuels.
>
> **Renewable** refers to natural resources that have a sustainable yield or harvest equal to, or less than, their natural productivity – for example, timber.

■ **QUICK CHECK QUESTIONS**

15 What was/is the most common energy source:
   a) in 1950
   b) in 2000
   c) projected for 2050
16 Which energy sources are predicted to show the most growth by 2050 compared with 2000?
17 Which of these are renewable and which are non-renewable?

Expert tip

Figure 3.7 is an example of a compound line graph. This means that the value for any category is drawn above the category below it. For example, the amount of coal used in 2000 was about 20 billion barrels of oil equivalent, not 60 billion. Oil was approximately 30 billion barrels and natural gas 10 billion, and so coal is drawn between 40 and 60. The value of a compound graph like this is that it shows you total (consumption of energy) as well as the relative contribution, in this case, of each of the energy resources.
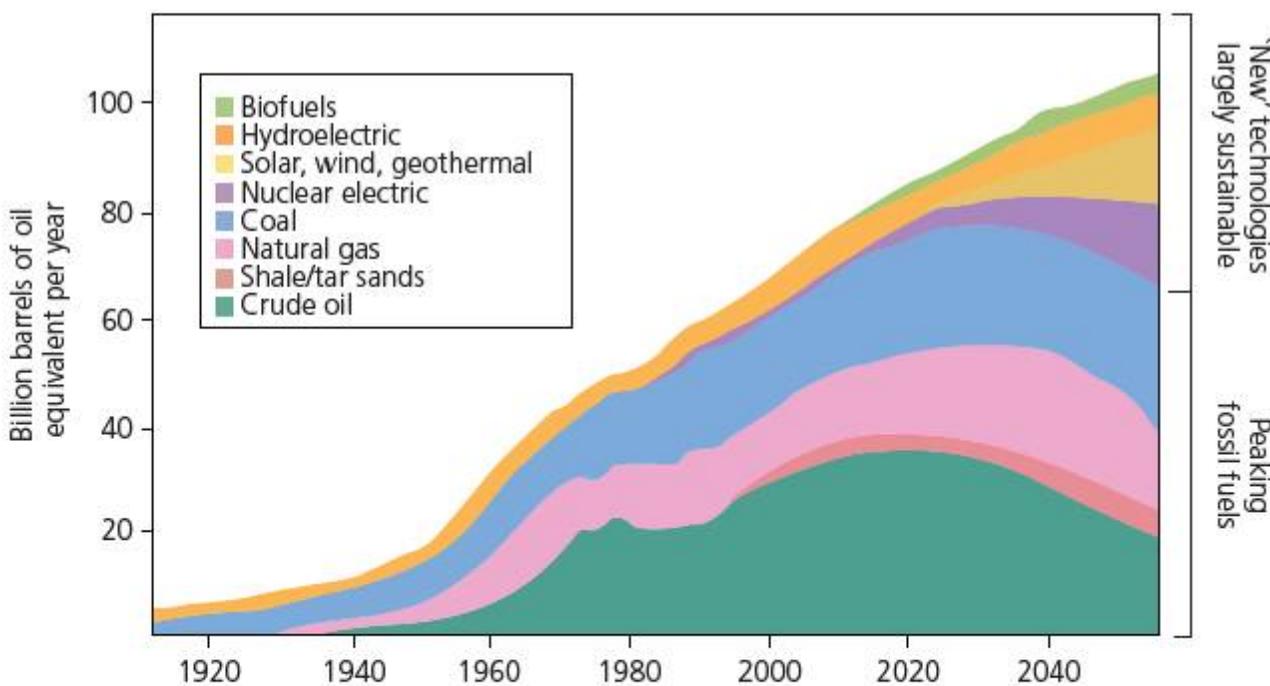

Figure 3.7 World energy demand – long-term energy sources

The advantages and disadvantages of contrasting energy sources

> **Key word definition**
> Fossil fuels are **non-renewable resources**. These are natural resources that can only be used once in a human lifetime – for example oil, coal, natural gas and shale gas.

> **Expert tip**
> It is not just the non-renewable forms of energy that contribute to global warming. Renewable forms such as biomass (fuelwood and dung) release CO_2. Many other forms, including HEP, tidal and nuclear, contribute to global warming in the construction of, in this case, dams, barrages and power stations.

Oil

Table 3.5 Advantages and disadvantages of oil

Advantages	Disadvantages
Oil has been a relatively cheap and efficient form of energy, and a versatile raw material.	The importance of oil as the world's leading fuel has had many negative effects on the natural environment. For example:
It is relatively easy to transport by tanker or pipeline.	■ oil slicks from tankers (e.g. Torrey Canyon (1967), Exxon Valdez (1987), Braer (1993) and drilling rigs (e.g. Deepwater Horizon (2010))
Oil **reserves** are generally found in geological structures such as anticlines, fault traps and salt domes.	■ damage to coastlines, fish stocks and communities dependent upon the sea
At present rates of production and consumption reserves could last for another 40 years.	■ water pollution caused by tankers illegally washing/ cleaning out tanks in the North Sea
Nearly two-thirds of the world's reserves are found in the Middle East.	■ Gulf War damage – storage of oil and oil wells can be targets for destruction, causing immeasurable environmental damage.
The Arctic is believed to have about 35% of the world's oil reserves.	It is a finite resource and will eventually run out – indeed we may already have experienced 'peak oil'.
	The burning of oil contributes to global warming through the release of CO_2.

Hydroelectric power (HEP)

Table 3.6 Advantages and disadvantages of HEP

Advantages	Disadvantages
Hydroelectric power (HEP) is a renewable form of energy that harnesses fast-flowing water with a sufficient volume.	HEP plants are very costly to build.
It is considered to be a clean form of energy as it does not emit greenhouse gases (although many are released during the construction of the dam).	Only a small number of places have a sufficient head of water.
	Markets are critical – the plant needs to run at full capacity to be economic.
HEP stations are often associated with aluminium smelters to use up excess energy.	Migratory fish and mammals may have their routes affected.
	There may be increased evaporation behind the dam and the deposition of silt.
	Diseases such as schistosomiasis can be spread by the stagnant water.
	Fish yields downstream can be adversely affected by the trapping of sediments behind the dam.

Nuclear power

Table 3.7 Advantages and disadvantages of nuclear power

Advantages	Disadvantages
Nuclear power accounted for about 9% of energy production in 2005. Nuclear energy has received support from the environmental movement in recent years. This has occurred for two reasons: ■ the prospect of global warming ■ nuclear power does not emit greenhouse gases.	Nuclear power stations are very expensive to build and have nearly always overrun on costs and time needed for completion. The decommissioning costs of obsolete nuclear power stations are enormous. There are serious risks related to radiation (e.g. Chernobyl, Fukushima). The 2011 Fukushima disaster in Japan led to Japan turning its back on nuclear power.

COMMON MISTAKE

Nuclear power is sometimes described as an 'alternative energy' along with renewable forms of energy such as HEP and wind. It is an alternative to fossil fuels as it does not release carbon dioxide but it is not a renewable form of energy – once uranium has been used it cannot be recycled or used again.

Coal

Table 3.8 Advantages and disadvantages of coal

Advantages	Disadvantages
Coal is mostly found in the mid-latitudes of the northern hemisphere and has been responsible for the development of western industrial growth. Thick, level, continuous seams are the most competitive and facilitate the use of machinery. The two principal users of coal as a fuel are production of electricity in thermal power stations and the smelting industry (e.g. iron and steel). Coal is also important in the chemicals industry and provides a range of products from aspirin to nylon. Coal is sometimes divided into two main types: coking coal and steam coal. Coking coal is used in the manufacture of iron and steel. Steam coal, however, is used to generate electricity. The demand for steam coal is rising rapidly.	Coal is dirty, bulky, costly and difficult to transport. Due to inefficiencies in early forms of transport and machinery, industries located on the coalfields. Coal has a negative impact upon the environment in a number of ways: ■ Open-cast mining causes serious visual and noise pollution. ■ Burning coal contributes to acid rain and to global warming.

Some of these disadvantages can be managed:
■ The introduction of precipitators and filters in smokestacks retains dust, sulfur dioxide and nitrogen oxides (NOx) within the chimney.
■ Sulfur emissions have declined by up to 95% and NOx emissions by 60%.

Solar power

Table 3.9 Advantages and disadvantages of solar power

Advantages	Disadvantages
No finite resources are involved. Less environmental damage is caused. No atmospheric pollution is given off. It is suitable for small-scale and large-scale production. Energy from the Sun is clean, renewable and so abundant that the amount of energy received by the Earth in 30 minutes is the equivalent to all the power used by humans in 1 year.	It is affected by cloud, seasons and daylength, so it cannot be guaranteed to work in all locations. It is not always possible where demand exists. The high costs of solar power make it difficult for the industry to achieve its full potential. At present it does not make a significant contribution to energy efficiency. Each unit of electricity generated by solar energy costs between 4 and 10 times as much as that derived from fossil fuels.

Wind power

Table 3.10 Advantages and disadvantages of wind power

Advantages	Disadvantages
Wind power is suitable for small-scale production. The only requirement is an exposed site, such as a hillside, flat land or close to the coast, where winds are strong and reliable. There is no pollution of air, ground or water. No finite resources are involved. It reduces environmental damage elsewhere.	Visual impact – although some people like the appearance of wind turbines, many dislike them They are noisy They can injure migrating birds. Winds may be unreliable. Large-scale development is hampered by the high cost of development, the large number of turbines needed, and the high cost of new transmission grids. Suitable locations for wind farms are normally quite distant from centres of demand.

Tidal power

Table 3.11 Advantages and disadvantages of tidal power

Advantages	Disadvantages
Tidal power is a renewable, clean energy source. It requires a funnel-shaped estuary, free of other developments, with a large tidal range. The River Rance in Brittany, France and the Bay of Fundy in Canada are good examples of where tidal power has been developed.	Large-scale production of tidal energy is limited for a number of reasons: ■ high cost of development ■ limited number of suitable sites ■ environmental damage to estuarine sites ■ long period of development ■ possible effects on ports and industries upstream.

Fuelwood

Table 3.12 Advantages and disadvantages of fuelwood

Advantages	Disadvantages
Biomass or living matter is a readily available source of fuel in some countries. It includes trees, crops, animal remains and animal waste. Fuelwood is the most important source of energy in rural Africa, due to its availability. For example in Tanzania it accounts for 90% of energy consumption, and in Zimbabwe 50%.	In many areas fuelwood availability is decreasing fast. As fuelwood becomes more scarce, women and children travel further to collect it and round trips of 10 km are not uncommon. This imposes an extra burden upon their health.

Expert tip

Try to make sure that your answers are balanced. If you have to answer a question on the advantages and disadvantages of a form of energy, make sure that you cover both sides and try to give as many advantages as disadvantages. You can still form a conclusion and give your views, while also recognising that others may have different views.

Expert tip

In the exams, you only have to consider one non-renewable resource (fossil fuels or nuclear) and one renewable energy source. Revise the ones you have studied in class.

A decline in fuelwood does not just mean pressure on time and labour. Trees are a multipurpose resource. They:

- are used to build houses
- provide fencing
- contribute to food supply
- supply drugs and medicines
- prevent wind and water erosion
- act a habitat for wild animals.

■ **QUICK CHECK QUESTIONS**

18 What are the advantages of fossil fuels?
19 What are the disadvantages of renewable forms of energy, such as HEP and wind?

Factors affecting the choice of energy sources adopted by different societies

There are many important factors to consider in the use of energy, relating to availability as well as economic, cultural, environmental and technological issues:

- Availability and reliability of supply – the UK used to have coal, then it had oil, but it has limited potential for solar or geothermal energy.
- Suitability and efficiency of supply – many poor countries are limited in their choice of energy source.
- Costs of production, distribution and use – is nuclear power or tidal energy too expensive?
- Type of market – industrial, agricultural or residential – energy demand soars as a country industrialises.
- Political factors – in 1973 OPEC (Organization of the Petroleum Exporting Countries) raised the price of oil, causing other countries to develop their own, cheaper resources.
- Demand for energy – this depends on a country's population size, wealth and level of industrialisation.
- Population growth – rapid population growth leads to more energy being used.
- Economic growth – rapid economic growth leads to more energy being used.
- Stage of development – less developed countries use a smaller amount of energy per head and more basic sources such as fuelwood, whereas developed countries use more energy and more expensive forms such as nuclear and oil.
- Climate factors – certain climates allow certain types of energy such as solar or wind power; colder climates require more heating.

Low levels of energy consumption per head in poor countries are explained by:

- lack of suitable resources
- lack of economic development to finance the rapid development of energy resources or imports of energy
- rapid growth of population (demand exceeds supply)
- lack of capital to develop alternative forms of energy
- debt
- lack of technological resources
- lack of trust, especially with regard to nuclear power
- lack of fuelwood.

Common mistake

Not all rich countries are the same – nor are all poor countries. It is very easy to over-generalise in an answer. Try to make sure that you refer to specific rich and poor countries and give some details about their energy consumption.

Expert tip

Make sure that you have two contrasting countries – a rich one and a poor one.
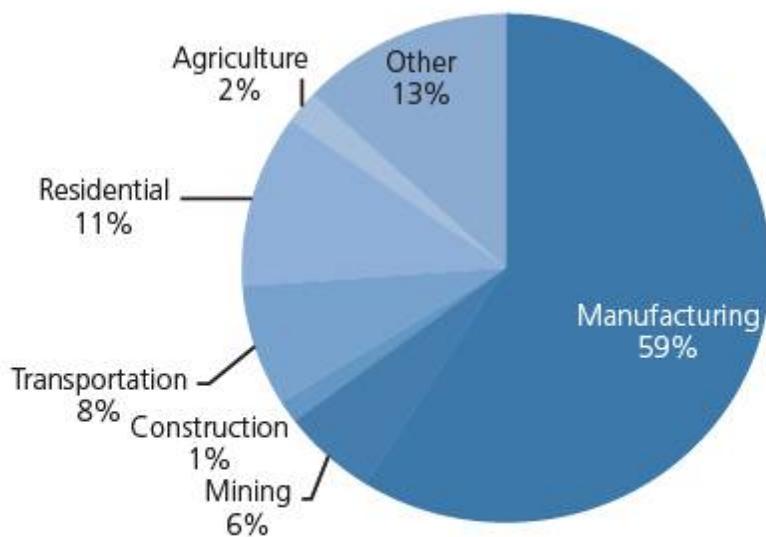
■ QUICK CHECK QUESTIONS

20 The diagram shows energy consumption in China by source.
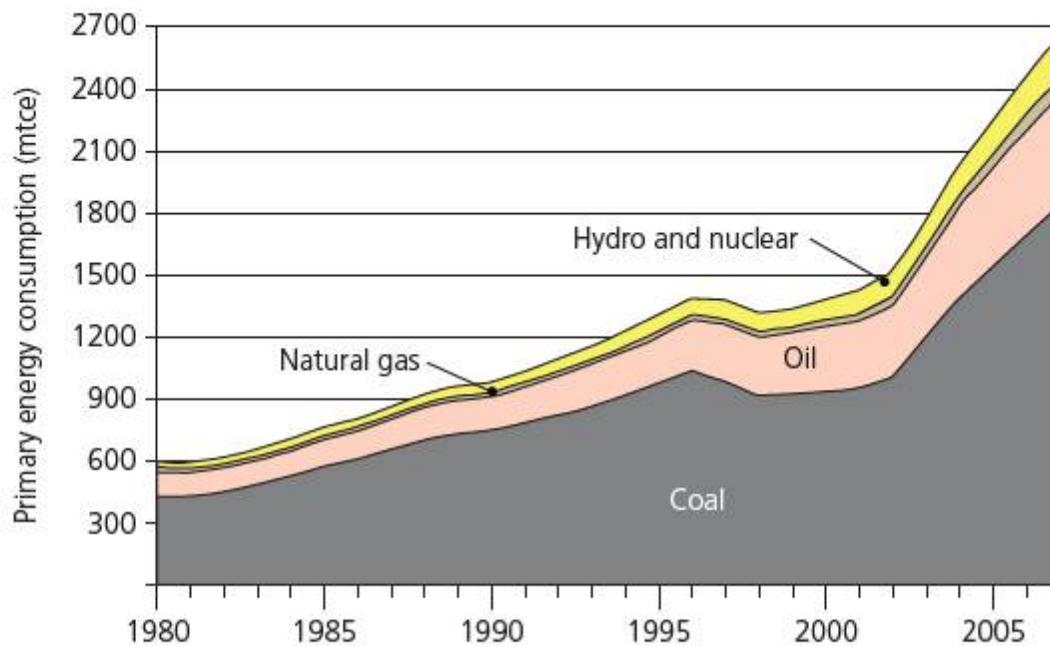
Describe the changes in China's energy sources, 1980–2005.

21 The diagram shows China's energy consumption by economic sector.

Describe the main features of China's energy consumption.

22 Outline the potential environmental impacts of China's energy use.

EXAM PRACTICE

10 Outline the advantages of **two** energy sources, and suggest why one plays a greater role in meeting energy needs than the other in a **named** country.   [5]

11 Evaluate the advantages and disadvantages of **two** contrasting energy sources and discuss the economic factors that affect the choice of these energy sources by different **named** societies.   [9]

The soil system

Revised □

Soil is the outermost layer of the Earth's surface, consisting of weathered bedrock (regolith), air, water and living organisms. Soil systems link the soil with the lithosphere, atmosphere and living organisms. Figure 3.8 illustrates some of these links.

> **Key word definition**
>
> **Soil** is a mixture of mineral particles and organic material that covers the land, and in which terrestrial plants grow.
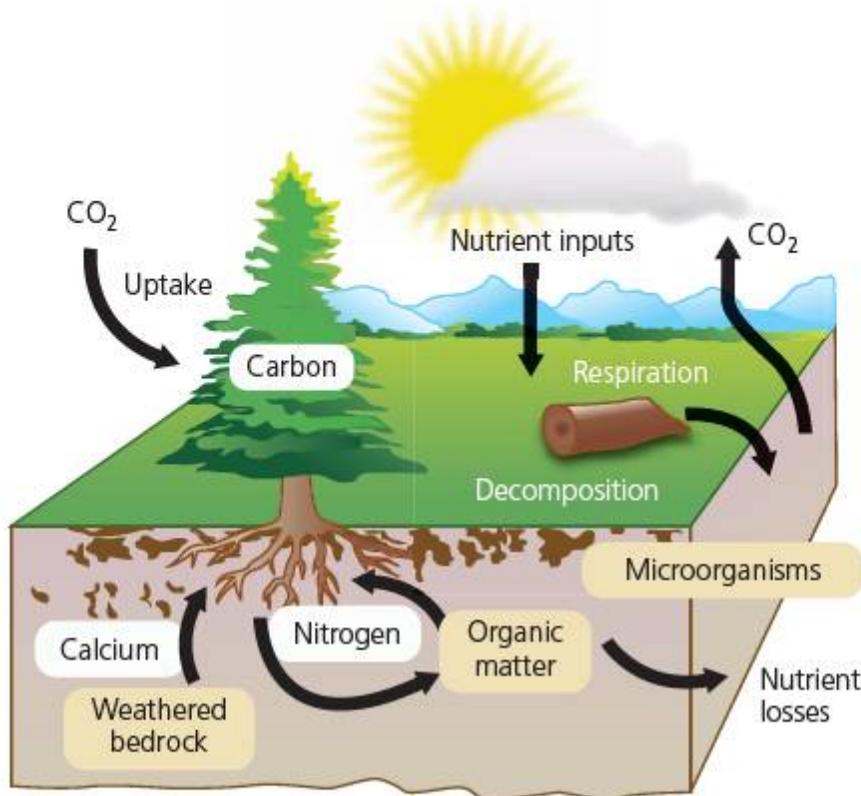
Figure 3.8 Soil systems, lithosphere systems and atmospheric systems

Soil processes are directly affected by atmospheric process. The amount of heat, evaporation and precipitation determine the main movements of water within the soil.

Lithospheric systems are also important – the **parent material** (bedrock) influences soil drainage and **soil fertility**.

The **soil profile** is influenced by biotic factors. Earthworms help mix the soil, while fungi and bacterial activity help break down plant litter and form humus.

> **Key word definition**
> A **soil profile** is a vertical section through a soil, from the surface down to the parent material, revealing the soil layers or horizons.
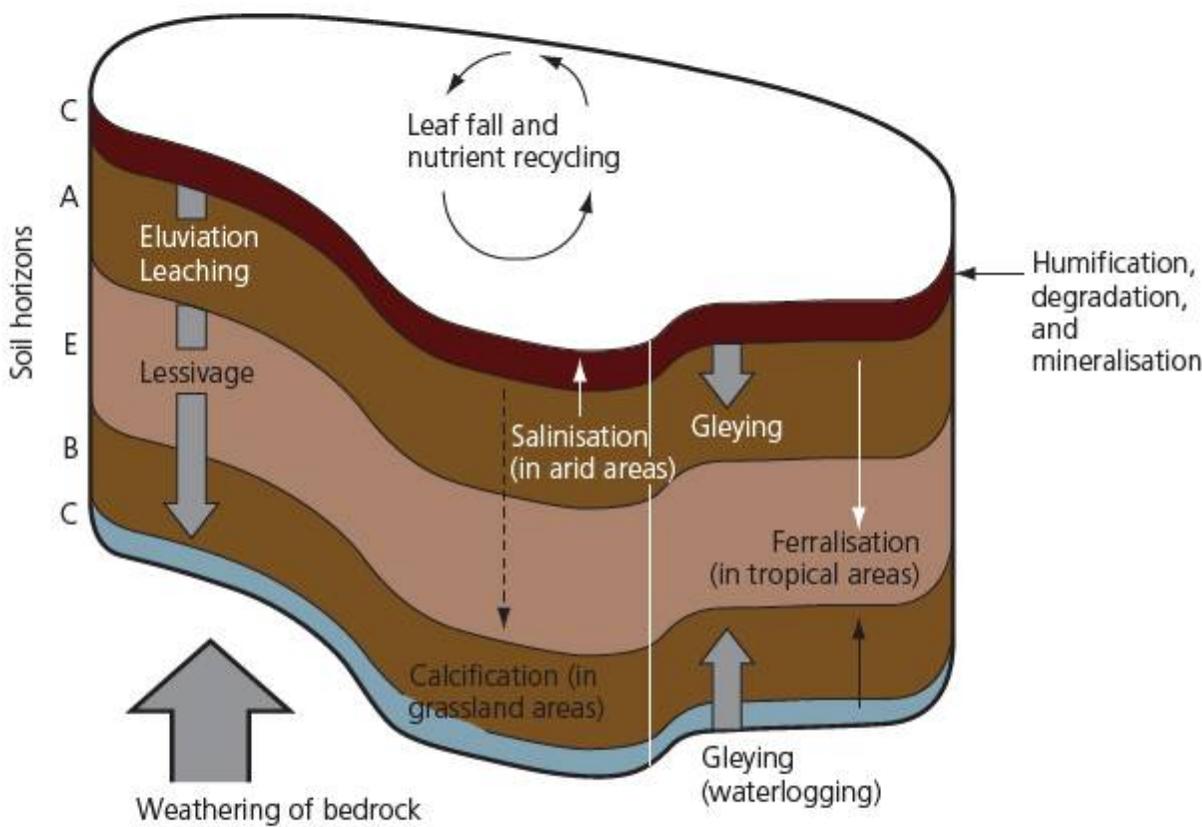
Figure 3.9 A soil profile

- The soil profile (Figure 3.9) shows distinct **soil horizons** – these include O (organic horizon), A (mixed mineral/organic horizon), E (eluvial or leached horizon), B (illuvial or deposited horizon) and C (bedrock or parent material).
- Transfers of material (including deposition) result in reorganisation of the soil.
- There are inputs of organic and parent material, precipitation, infiltration and energy.
- Outputs include leaching, uptake by plants and mass movement.
- **Leaching** generally refers to the removal of material down a soil through solution and suspension. (Leaching, illuviation and eluviations are often used interchangeably but they have precise definitions.)

- Transformations include decomposition, weathering and nutrient cycling.
- **Humification**, **degradation** and **mineralisation** form the process whereby organic matter is broken down and the nutrients are returned to the soil. The breakdown releases organic acids – chelating agents – which break down clay to silica and soluble iron and aluminium.
- **Illuviation** is the redeposition of material in the lower horizons.

Expert tip

Make sure that you can draw diagrams such as Figures 3.8 and 3.9 that show the soil system and how processes might take place within a soil.

> ■ **QUICK CHECK QUESTIONS**
> 23 Define the term *soil*.
> 24 Identify **two** ways in which bedrock influences soils, and **two** ways in which climate affects soils.

Soil characteristics

Revised ▢

Soil structure and texture

- **Soil structure** refers to the shape of the particles. It has an effect on primary productivity.
- **Soil texture** refers to the size of soil particle.
- Sand particles are those less than 2 mm in diameter, silt less than 0.02 mm and clay less than 0.002 mm.
- Soil textural groups are often shown by the use of triangular graphs (Figure 3.10).

Common mistakes

Triangular graphs are often read incorrectly – the sum of the percentages must add up to 100%.
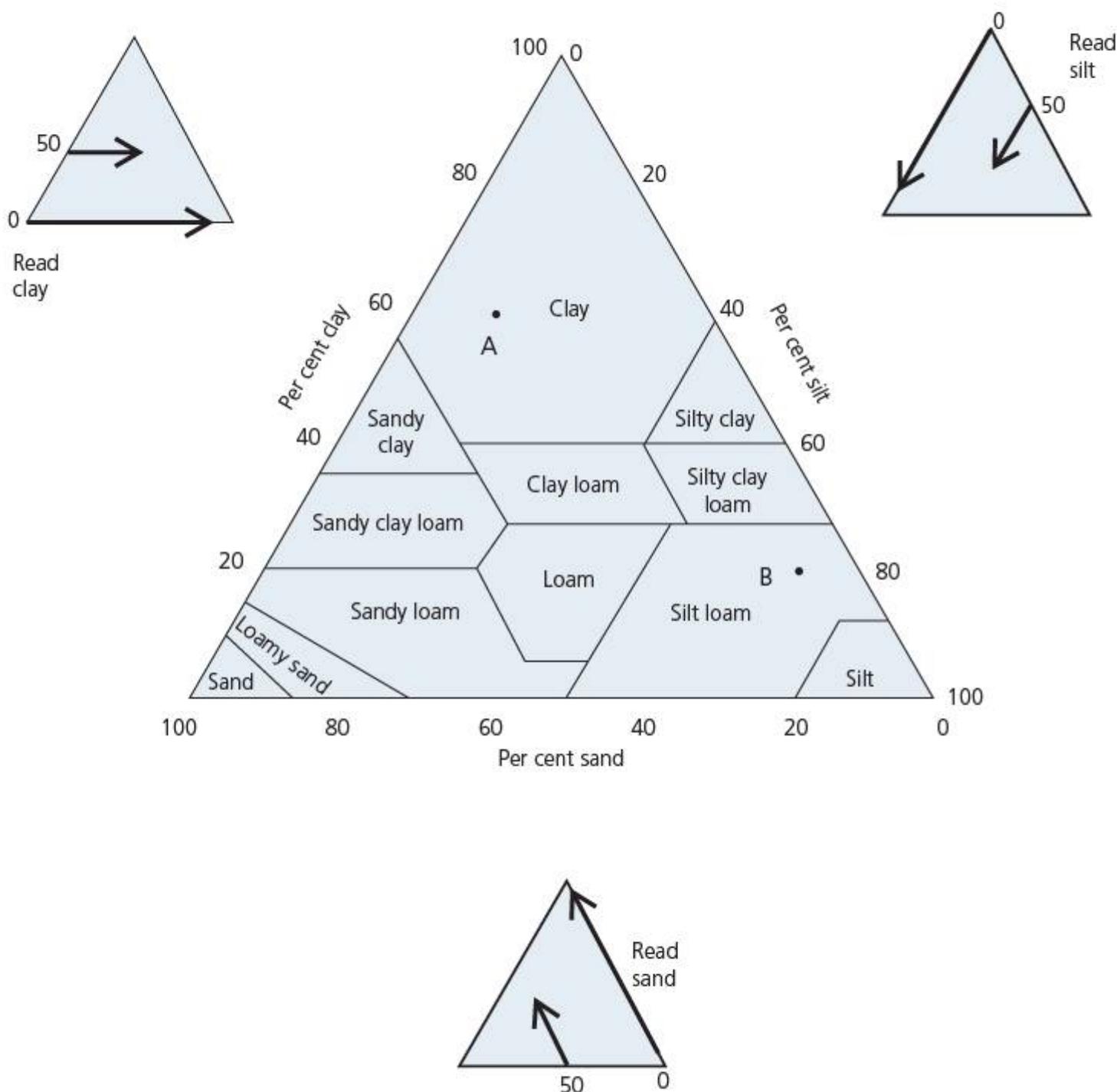
Figure 3.10 A triangular graph to show soil textural groups

- Soil texture is important as it affects: moisture content and aeration; retention of nutrients; and ease of cultivation and root penetration.
- Clay soils have a large surface area in relation to volume and so have a high potential for exchange of nutrients, but they become waterlogged, and are described as 'cold' or 'heavy'. In years of drought the shrinkage of some clay soils can cause structural damage.
- Sandy soils drain rapidly, and are described as 'light'.
- Silt soils are especially prone to compaction if ploughed when wet.
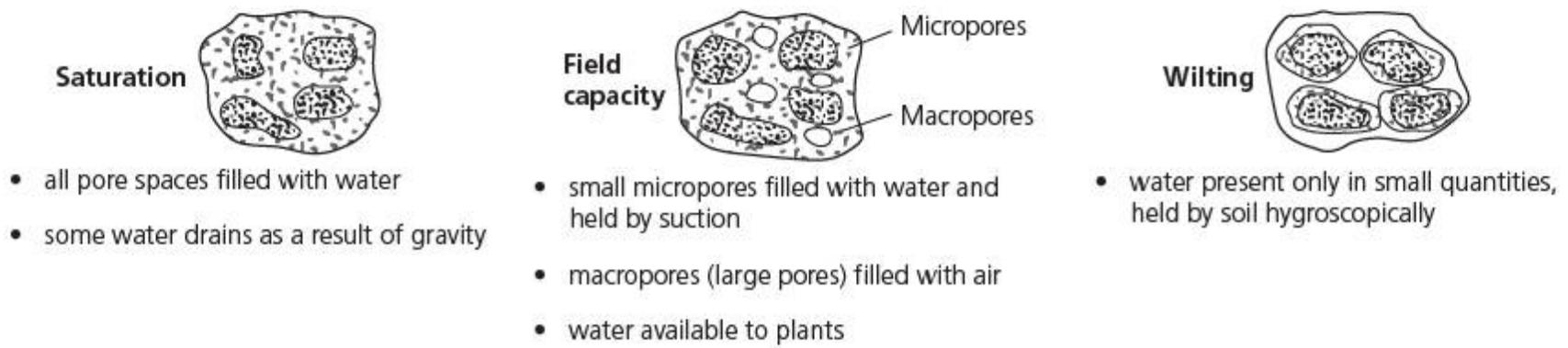- The maximum amount of water that a soil can hold is referred to as **field capacity** (Figure 3.11).

Saturation
- all pore spaces filled with water
- some water drains as a result of gravity

Field capacity
Micropores
Macropores
- small micropores filled with water and held by suction
- macropores (large pores) filled with air
- water available to plants

Wilting
- water present only in small quantities, held by soil hygroscopically

Figure 3.11 Soil moisture

A loam soil is often considered to be the best soil for cultivation as it has the optimum combination of sand, silt and clay. It is therefore easily workable, drains well, retains moisture and nutrients and is well aerated. As a result, it has the highest plant productivity.

Table 3.13 Storage capacity of soils (cm water per 30cm depth)

Soil texture	Field capacity	Wilting point	Available water
Sandy loam	5.6	2.8	2.8
Loam	8.4	4.3	4.1
Clay loam	9.9	5.3	4.6
Heavy clay	11.9	6.3	5.6

■ **QUICK CHECK QUESTIONS**
25 Identify the percentage of sand, silt and clay found in soils A and B in Figure 3.10.
26 State what textural group each of the following soils belongs to:
   a) 60% sand, 30% clay and 10% silt
   b) 40% sand, 40% silt and 20% clay
27 Which of the soils in Table 3.13 is more likely to require irrigation to help plant productivity?

Expert tip
Make sure you study the textural groups. A 'clay' soil might only have 40% clay, and a mixed soil (loam) might only have as little as 10% clay. Some of the textural classes (groups) contain a wide variation of percentages.

Soil degradation

Revised

Human activities such as overgrazing, deforestation, unsustainable agriculture and irrigation cause processes of **soil degradation** (Figure 3.12). These processes include:
- **erosion** by wind and water. There are many types of water erosion including surface-, gully-, rill- and runnel-erosion.
- **biological degradation** (the loss of humus and plant/animal life)
- **physical degradation** (loss of structure, changes in permeability). Groundwater over-abstraction, for example, may lead to dry soils, leading to physical degradation.
- **chemical degradation** (acidification, declining fertility, changes in pH, salinisation and chemical toxicity). Acidification is a change in the chemical composition of the soil that can trigger the circulation of toxic metals.

Salinised (salt-affected) soils are typically found in marine-derived sediments, coastal locations and hot arid areas where capillary action brings salts to the upper part of the soil. Soil salinity has been a major problem in Australia following the removal of vegetation in dry land farming. Atmospheric deposition of heavy metals and persistent organic pollutants can make soils less suitable to sustain the original land cover and land use.

Desertification (enlargement of deserts – see below) can be associated with this degradation. Climate change will probably intensify the problem, as it is likely to affect hydrology and hence land use.
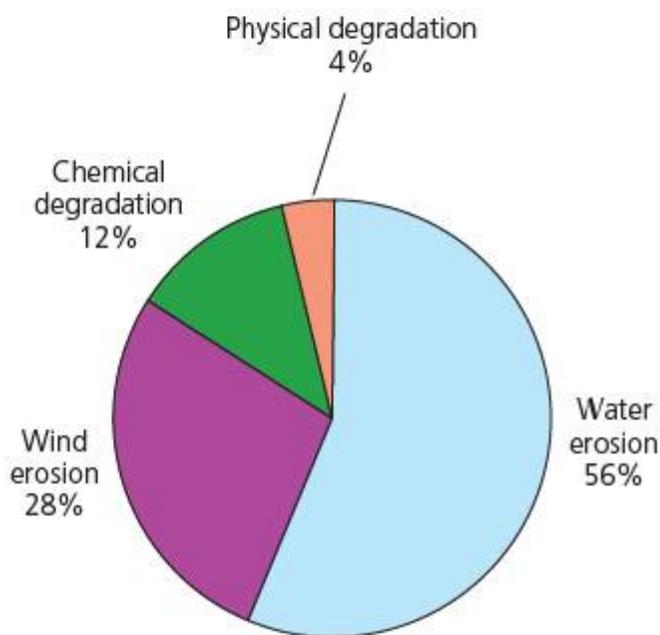
Figure 3.12 Types of soil degradation

Land degradation

Land degradation is a decline in land quality and its productivity.

Overgrazing and agricultural mismanagement affect more than 12 million km² worldwide. 20% of the world's pastures and rangelands have been damaged and the situation is most severe in Africa and Asia. Huge areas of forest are cleared for logging, fuelwood, farming or other human uses.
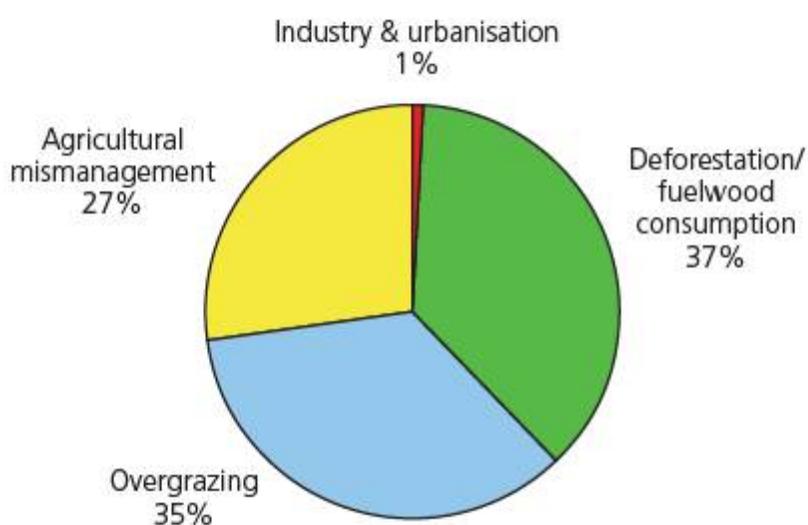

Figure 3.13 Types of land degradation

Desertification

Desertification is the spread of desert-like conditions into previously green areas, causing a long-term decline in biological productivity.
- It can be natural, but increasingly it is the result of human activities.
- It occurs in rich countries such as the USA, Australia and Spain, as well as poor countries such as Burkina Faso, Mali and Ethiopia.
- Changes in agriculture, such as the concentration of livestock herds near boreholes, are partly responsible for desertification.
- It has major social, economic and environmental impacts.

- Social impacts can include increased hunger, reduced performance at school and increased illness.
- Economic impacts include reduced crop yields, falling incomes and reduced ability to work.
- Environmental impacts include reduced soil cover, decreased soil organic content, reductions in soil moisture availability and increased potential for soil erosion.

■ **QUICK CHECK QUESTIONS**

28 What proportion of soil degradation is caused by water and wind erosion?
29 Suggest **two** economic and **two** social impacts of desertification.

Soil conservation measures

Revised ☐

Soil conservation measures include:
- abatement techniques such as afforestation
- soil conditioners (for example, use of lime and organic materials)
- wind reduction techniques (wind breaks, shelter belts, strip cultivation)
- cultivation techniques (terracing, contour ploughing)
- efforts to stop ploughing of marginal lands.

Many of these are used in combination.

Managing soil degradation

- Abatement strategies for combating accelerated soil erosion, such as afforestation, are lacking in many areas.
- To reduce the risk of soil erosion, farmers are encouraged towards more extensive management practices such as organic farming, afforestation, pasture extension and benign crop production.
- Methods to reduce or prevent erosion can be mechanical, including physical barriers such as embankments and wind breaks, or they can focus on vegetation cover and soil husbandry.
- More vegetation cover increases infiltration and reduces overland flow.

Mechanical methods

- Mechanical methods include bunding, terracing, contour ploughing and shelterbelts such as trees or hedgerows.
- The key is to prevent or slow the movement of rainwater downslope.
- Contour ploughing forms at right angles to the slope to prevent or slow the downward accretion of soil and water.
- On steep slopes and in areas with heavy rainfall, such as the monsoon in Southeast Asia, contour ploughing is insufficient and terracing is undertaken. The slope is broken up into a series of flat steps, with bunds (raised levées) at the edge.
- The use of terracing allows areas to be cultivated that would not otherwise be suitable.
- In areas where wind erosion is a problem shelterbelts of trees or hedgerows are used.
- The trees act as a barrier to the wind and disturb its flow. Wind speeds are lowered, which reduces its ability to disturb the topsoil and erode particles.

Cropping techniques

Preventing erosion by different cropping techniques largely focuses on:
- maintaining a crop cover for as long as possible
- keeping in place the stubble and root structure of the crop after harvesting
- planting a grass crop – grass roots bind the soil, minimising the action of the wind and rain on a bare soil surface. Increased organic content allows the soil to hold more water, thus preventing aerial erosion and stabilising the soil structure.

Salt-affected soils

There are three main approaches in the management of salt-affected soils:

- flushing the soil and leaching the salt away
- application of chemicals, for example gypsum (calcium sulfate) to replace the sodium ions on the clay and colloids with calcium ions
- a reduction in evaporation losses to reduce the upward movement of water in the soil.

Equally specialist methods are needed to decontaminate land made toxic by chemical degradation (see also eutrophication on pages 108–110).

■ QUICK CHECK QUESTIONS

30 Identify **four** types of soil conservation.
31 Briefly explain how afforestation acts as a measure of soil conservation.
32 State **two** soil conservation measures that could be taken to prevent desertification.

Soil management strategies in subsistence and commercial farming systems

Shifting agriculture in tropical rainforest is an example of subsistence farming. Soils in the tropical rainforest are very infertile. The high temperatures and high rainfall produce deeply weathered and leached soils that are lacking in nutrients.

The long growing season and intense competition among plants means that most of the available nutrients are held by the biomass (trees). To increase the fertility of the soil, cultivators cut down ('slash') the vegetation and burn it, thereby releasing some of the nutrients into the soil. This increases the soil fertility in the short-term and allows agriculture to take place.

Over the following few years, these nutrients are washed away and the soil fertility drops. This forces the cultivators to abandon the plot they are farming and move to another plot – hence the term 'shifting cultivation'.

Some researchers believe that shifting cultivation may lead to long-term decline in soil fertility (Figure 3.14b) rather than being sustainable (Figure 3.14a).
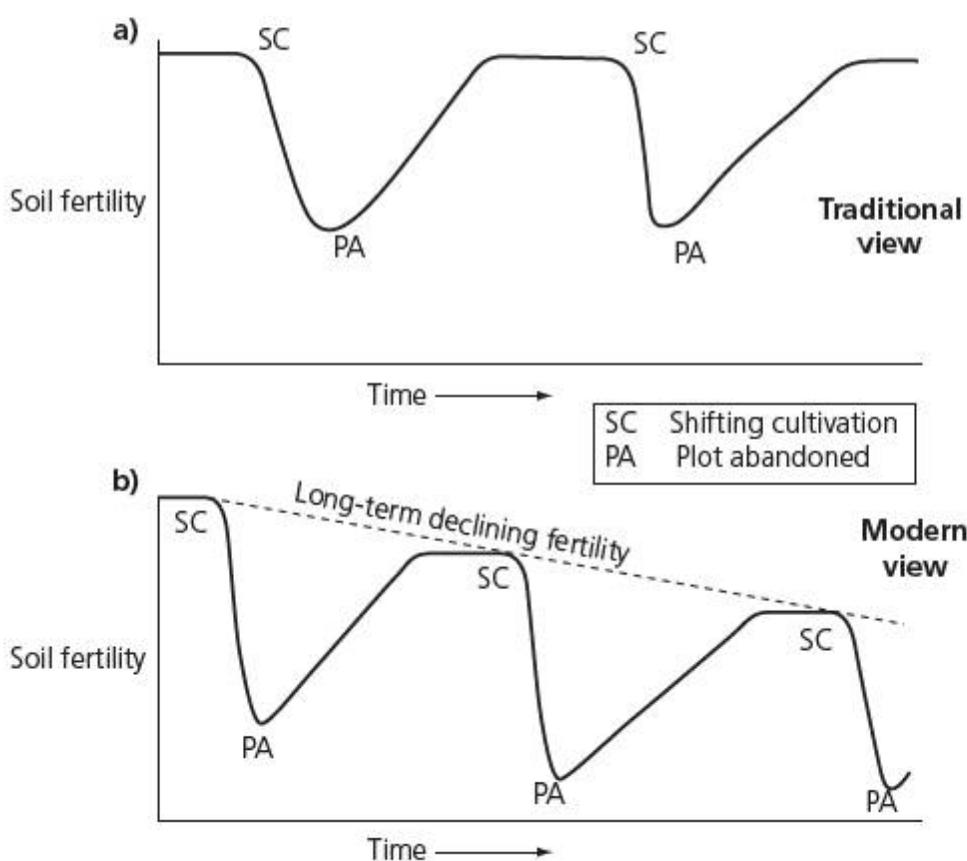

Figure 3.14 Effects of shifting cultivation on soil fertility

Expert tip

Attempts to achieve soil conservation can be affected by population growth and the need to produce more food, climate change and poverty-reduction schemes.

Common mistake

The tropical rainforest has been described as 'a desert covered by trees'. There is a paradox in that some of the world's most luxuriant vegetation is found on some of the world's least fertile soils. This is explained by the way in which most of the nutrients are held by the trees.

CASE STUDY

SOIL CONSERVATION ON THE GREAT PLAINS OF THE USA
The Great Plains of the USA experienced severe droughts in the 1930s, and the soils suffered severe wind erosion. Soil conservation techniques included:

- contour ploughing
- strip cultivation with an alternation of cultivated and fallow (crop-free) land
- temporary cover crops, such as a fast-growing millet
- shallow ploughing to eliminate weeds and conserve crop residues on the surface
- summer fallow to regenerate soil nitrogen as well as conserve moisture
- some areas being converted to permanent grazing
- use of a 'grass-break' to help stabilise soils by the accumulation of organic matter.

However, since the end of the Second World War, the introduction of herbicides has:

- made weed control possible
- reduced the risk of soil erosion
- reduced nitrogen loss
- increased salinity problems due to increased soil water evaporation.

Expert tip

You must have an example of **one** commercial farming system and **one** subsistence system.

■ **QUICK CHECK QUESTIONS**
33 In what ways is shifting cultivation a response to the soils of the tropical rainforest?
34 Identify **three** forms of soil conservation that were used on the Great Plains.

EXAM PRACTICE

12 Explain the importance of soil organisms in ecosystems.   [5]
13 Outline how soil degradation can be caused by human activities.   [5]

Food resources

Revised ☐

Issues involved in the imbalance in global food supply

Revised ☐

There are many differences in food production and distribution around the world, which are affected by a range of socio-political, economic and ecological influences.

- The world is growing by over 80 million people each year, hence more food is needed.
- In addition, a larger proportion of people in the world will become middle- and high-income earners, and there will be a corresponding change in diet from grain-based to meat- and dairy-based.

During the latter part of the twentieth century, the growth in food production out-paced the growth of population. This was largely due to the **Green Revolution** (the application of science and technology to agriculture, leading to high-yielding varieties, breeding programmes, widespread use of chemical fertilisers and pesticides, irrigation and so on).

However, between 2001 and 2008 world food prices rose dramatically. Although there was an increase in food production, there was an even greater increase in demand for food. A rise in oil prices led to higher costs in transport and fertiliser production.

Common mistakes

It is not just population growth that causes an increased demand for food – standard of living is important too. The gradual change in diet by people in newly rich and industrialising countries (such as Korea and, increasingly, China and India) is one of the most important factors leading to a relative food shortage.

The impact of biofuels

Another cause of the rise in food prices is the use of land for the production of biofuels rather than food crops. Approximately 100 million tonnes of grain are used for biofuels. As more grain is used for biofuel, less grain (and land) is used for the production of food for human use.

Natural hazards

Many on-going natural hazards are having an impact on food production. For instance some of the countries that make the most money out of farming (the USA, China, India, Australia) have had recurring drought, leading to falling production.

Food distribution

Once food is produced it needs to be brought to the market to be sold. Sometimes food is collected from the farmer whereas at other times the farmer has to get it to the market. This uses fossil fuels in the transport. The distance that a food travels to its destination is known as **food miles**. Some foods are transported huge distances.

In addition, all of the inputs, such as fertilisers, machinery and equipment, need to be transported to the farmer. These are expensive and also use up fossil fuels.

> ### ■ QUICK CHECK QUESTIONS
> 35 How was agricultural production in the twentieth century able to grow more rapidly than population growth?
> 36 Suggest reasons for the falling level of productivity after about 2004.

Expert tip

If a food has more food miles, this does not mean it is more harmful to the environment than one that is consumed locally. A locally grown food might use more fertiliser and irrigation water and provide less return per unit of input.

The efficiency of terrestrial and aquatic food production systems

Revised ☐

Terrestrial and aquatic food production systems (Figure 3.15) vary in terms of their trophic levels and efficiency of energy conversion.
- In terrestrial systems, most food is harvested from relatively low trophic levels (producers and herbivores).
- In aquatic systems most food is harvested from higher trophic levels where the total storages are much smaller. Although energy conversions along the food chain can be more efficient in aquatic systems, the initial fixing of available solar energy by primary producers tends to be less efficient due to the absorption and reflection of light by water.
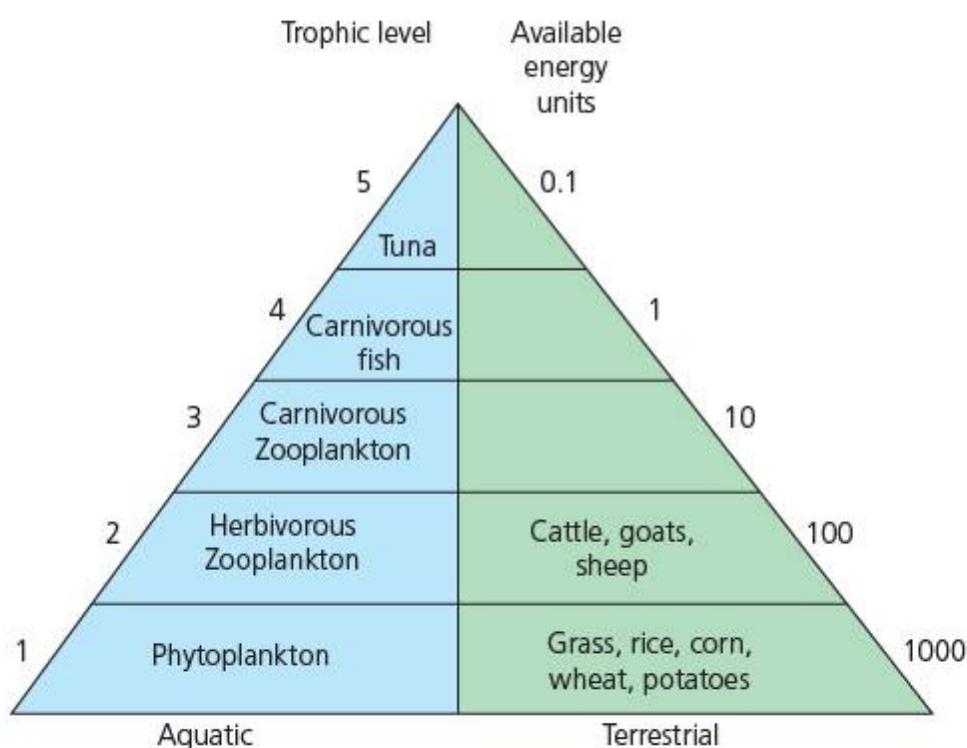

Figure 3.15 showing a pyramid with Trophic level and Available energy units:

Trophic level	Aquatic	Terrestrial	Available energy units
5	Tuna		0.1
4	Carnivorous fish		1
3	Carnivorous Zooplankton		10
2	Herbivorous Zooplankton	Cattle, goats, sheep	100
1	Phytoplankton	Grass, rice, corn, wheat, potatoes	1000

Figure 3.15 Aquatic and terrestrial farming systems

Terrestrial farming systems

Terrestrial farming systems can be classified according to four pairs of contrasting categories:
- **arable** (the cultivation of crops, e.g the corn belt in the USA) or **pastoral** (the rearing of animals, e.g. the Maasai herdsmen of Kenya)

Common mistake

The focus on productivity and/or efficiency may be over-simplistic. For example, prawn farming has led to the destruction of about one-third of the world's mangrove forests and this can have a knock-on effect on fishery production in nearby ecosystems.

- **commercial** (products are sold to make a profit, e.g. market gardening in the Netherlands) or **subsistence/peasant** (products are consumed by the cultivators, e.g. shifting cultivation by the Kayapo of the Amazonian rainforest)
- **intensive** (high inputs or yields per unit area, e.g. cattle feed lots in California) or **extensive** (low inputs or yields per unit area, e.g. reindeer herding in Siberia)
- **nomadic** (farmers move seasonally with their herds, e.g. the Pokot pastoralists in Kenya) or **sedentary** (farmers remain in the same place throughout the year, e.g. rice farmers in southeast Asia).

> ### ■ QUICK CHECK QUESTIONS
> 37 Describe the dairy farming system and the nomadic pastoralist system using the four sets of contrasting terms described in the text.
> 38 Which are more efficient, terrestrial ecosystems or aquatic ecosystems? Give reasons to support your answer.

> **Expert tip**
>
> The classification of farming into four dichotomous ('either/or') categories is an over-simplification. A subsistence farmer may sell a small amount of produce whereas a commercial farmer may keep some farm produce for home consumption. Each pair should be seen as a sliding scale from one to the other.

Contrasting food production systems

`Revised` ☐

Factors to be considered when contrasting two food production systems should include:
- inputs – for example, fertilisers (artificial and natural), irrigation water, pesticides, fossil fuels, food distribution, human labour, seed, breeding stock
- system characteristics – for example, selective breeding, genetically engineered organisms, monoculture versus polyculture, sustainability
- socio-cultural – for example, for the Maasai cattle equals wealth, and quantity is more important than quality
- environmental impact – for example, pollution, habitat loss, reduction in biodiversity, soil erosion.

> **Expert tip**
>
> When contrasting two systems, those you choose should be both terrestrial or both aquatic. In addition, the inputs and outputs of the two systems should differ qualitatively and quantitatively (although not all systems will be different in all aspects). A pair of examples could be, for example: North American cereal farming and subsistence farming in some parts of Southeast Asia; intensive beef production in the developed world and the Maasai tribal use of livestock; or commercial salmon farming in Norway/Scotland and rice-fish farming in Thailand. Other local or global examples are equally valid.

Table 3.14 Factors affecting agriculture

Physical factors	Socio-economic factors
Precipitation: type, frequency, intensity, amount	Land tenure/ownership: ownership, rental, share-cropping, state-control
Temperature: growing season (>6°C), ground frozen (0°C), range of temperatures	Organisation: collective, cooperative, agribusiness, family farm
Soil: fertility (pH, cation exchange capacity), nutrient status, structure, texture, depth	Government policies: subsidies, guaranteed prices, ESAs (environmentally sensitive areas), quotas, set-aside
Pests: vermin, locusts, disease	War, disease, famine
Location: slope gradient, relief, altitude, aspect – ubac (shady) or adret (sunny)	Farm size: field size and shape
	Demand: size and type of market
	Capital: equipment, machinery, seed, money, 'inputs'
	Technology: HYVs, fertilisers, irrigation
	Infrastructure: roads, communications, storage
	Advertising
	Cultural and traditional influences
	Education and training
	Behavioural influences
	Chance
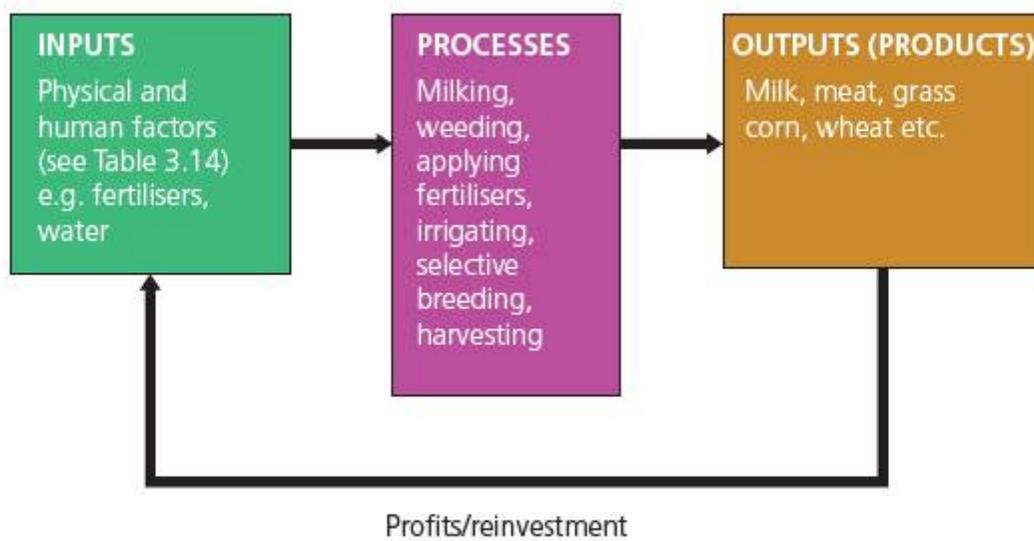
Figure 3.16 The farming system

CASE STUDY

SHIFTING CULTIVATION IN MEXICO

The Popoluca Indians of Santa Rosa, Mexico, practise a form of shifting cultivation. This farming system is intensive, subsistence, largely arable and semi-nomadic (they change plots every few years). Most of the labour is done by hand, with men doing the cutting, burning and hunting and women doing most of the farming.

The plots are quite small, typically 3–4 ha. These are cleared for farming by cutting down and burning trees, which enriches the soil with nutrients. However, most trees and shrubs are not burned, but are harvested for their fruits and seeds. The system produces over 250 different types of crops (polyculture). Those cultivated include coffee, oregano, squash and yams. The only input that is bought in is maize seed; the rest is from natural forest that is allowed to seed itself.

The men hunt for game, fish and turtles. There is some trading of surplus game. Fruit and insects are also gathered from the forest.

The system uses natural fertiliser (animal manure) as well as the burning of trees to enrich the soil. No irrigation water or pesticides are used, so no fossil fuels are needed. Energy ratios (energy outputs/energy inputs) may be as high as 65. The efficiency ratio (kg of feed/kg of total live weight) for insects and poultry is between 1.5 and 2.2.

There are some environmental impacts – for example, the cutting down and burning of vegetation is believed to have long-term effects on the quality of the soil (see Figure 3.14 on page 62).

CASE STUDY

INTENSIVE COMMERCIAL PIG PRODUCTION IN DENMARK

Pig farming in Denmark, an MEDC, is commercial, pastoral, intensive and sedentary. The system, based on the selective breeding, rearing and selling of stall-fed pigs, is heavily mechanised, with extensive use of food concentrates, machinery for feeding and transport services. Inputs also include veterinary services, the use of hormones to increase productivity and antibiotics to reduce the spread of disease.

Farms are generally between 10 ha and 30 ha in size. The work structure is increasingly based on a farm manager and hired labour. Many farms will also produce cereals and keep a dairy herd – skimmed milk and whey are fed to the pigs. The system is still classified as a monoculture because it is not diverse.

Energy ratios (outputs/inputs) are only around 0.4, while efficiency ratios (kg of feed/kg of total live weight) can reach 5.8.

The system is a commercial one – over nine million pigs are produced annually. Up to 75% of Danish bacon is exported and this accounts for 43% of Danish agricultural export.

The environmental impacts of this system are high:

- There is much use of fossil fuel in the distribution of pig products around the world and in the running of machines. Fossil fuels are also used in the production of feed concentrates.
- A large amount of manure is produced, the smell of which can impact on the local population of humans. It also produces methane as it decomposes.
- Fertilisers, pesticides and irrigation water are used to improve crop yields.

■ **QUICK CHECK QUESTIONS**

39 In what ways is shifting cultivation intensive?

40 How does this differ from intensive commercial food production?

Links between social systems and food production

There are many examples of links between social systems and food production systems.

- In some LEDCs low population densities are associated with shifting cultivation and nomadic pastoralism.
- In MEDCs such as the USA and Australia, low population densities may be associated with highly mechanised commercial farming.
- In areas of high population densities, such as in Southeast Asia, intensive farming has resulted.

Nomadic pastoralism

- Traditional nomadic pastoralists, such as the Pokot of Kenya, live out their lives in relative harmony with the natural environment. For example, the energy flow in the nomadic system is similar to that of the savannah ecosystem.
- Herdsmen use the savannah grasslands to feed their herds.
- Cattle replace wild herbivores as the main herbivores.
- There is limited killing of wild predators.
- The nutrient cycling system can be altered.
- True nomadic movement returns and distributes nutrients over a wide area although some concentrations of nutrients, in dung, can occur if herds remain in one place for a length of time, such as at a borehole.
- Biological productivity in savannah grasslands is low and variable.
- NPP varies from about $150\,g/m^2/year$ in drier areas, rising to $600\,g/m^2/year$ in wetter margins.
- Secondary productivity is low – hence farmers use milk, milk products and blood rather than meat.
- Their animals are their source of wealth so they only kill the very old or very sick.
- Environmental impacts might be unsustainable.
- Over-exploitation of grass or over-concentration of herds removes vegetation, especially sweeter species, causing ponding of the surface, gulleying and desertification – the spread of desert conditions (Figure 3.17).
- In traditional pastoral societies desertification has been due to climatic deterioration. Now, however, economic, social and political reasons are increasingly to blame. These have led to larger herds, shorter nomadic routes and greater pressure around water sources such as boreholes.

Modern agribusiness (agro-ecosystems)

- Unlike traditional subsistence farming, where the farmers do not own the land but have rights to use it, in modern agriculture there is generally some form of ownership (which may or may not then be rented to another farmer).
- Modern agribusiness is associated with capitalism and the drive to make profits.
- Increasingly farming is being driven by the demands of large retailers to provide high volumes of uniform-quality food to an increasingly urban population.
- Food production and distribution have gone global.
- Farming has become increasingly intensive, large-scale and globalised in the drive for cheaper food.
- Advances in technology and communications have combined with falls in the costs of transport to transform the way in which food is sourced.
- The concentration of power in retailing and food processing has affected those at the other end of the scale, namely farmers in LEDCs and small farmers in MEDCs.
- Increasingly, modern farming methods are having a negative impact on the environment.
- The term **agro-industrialisation** refers to the large-scale, intensive, high-input, high-output, commercial nature of much of modern farming.
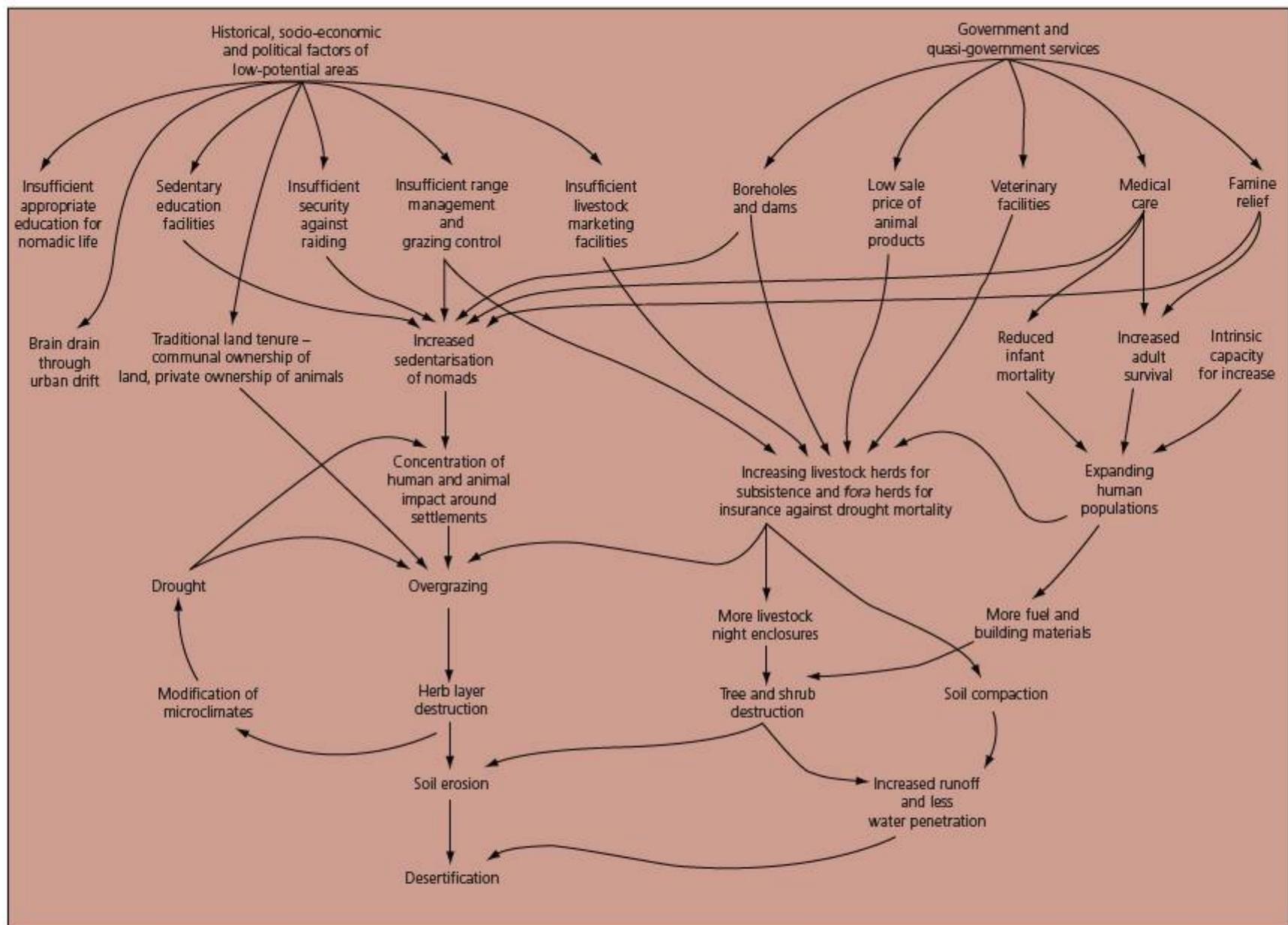
Figure 3.17 Some causes of desertification

Improved yields and environmental impacts

■ Since the 1960s, wheat yields have increased from 2.6 to 8 tonnes per hectare and barley yields from 2.6 to 5.8 tonnes, while each cow produces twice as much milk.

■ Cleaning up the chemical pollution, repairing the habitats and coping with disease caused by industrial farming costs up to £2.3 billion a year.

■ It now costs water companies £135–200 million to remove pesticides and nitrates from drinking water.

■ Food processors usually want large quantities of uniform-quality produce or animals at specific times. This is ideally suited to intensive farming methods, which favour synthetic chemicals, land degradation and animal welfare problems. For example, apples receive an average of 16 pesticide sprays.

■ The global food industry has a massive impact on transport.

■ The food system has become almost completely dependent on crude oil, making food supplies vulnerable, inefficient and unsustainable.

Common mistake

It is easy to see nomadic pastoralists as the victims of flower cultivation in Kenya. However, the pressures they face are much more diverse and complex (see Figure 3.17). In addition, there are benefits of modern agricultural systems, such as the mass production of food for urban areas, although the benefits are mainly for urbanites, and for those living in MEDCs and NICs (newly industrialising countries).

CASE STUDY

WATER PROBLEMS AND GLOBAL FARMING IN KENYA

The shores of Lake Naivasha in the 'Happy Valley' area of Kenya have been seriously polluted. Environmentalists blame the problems on pollution from pesticides, excessive use of water on farms and deforestation caused by migrant workers in the growing shantytowns foraging for fuel.

British and European-owned flower companies in the area grow vast quantities of flowers and vegetables for export. Much water is used to produce flowers. The export of these flowers (a flower is 90% water) is effectively exporting Kenyan water. This is known as 'virtual water'.

The greatest impact is being felt by the nomadic pastoralists in the semi-arid areas to the north and east of Mt Kenya. The flower farms have taken over land that the pastoralists used and there is now less water.

Expert tip

A useful approach when comparing two contrasting systems is to try to link them – the effects of flower cultivation in Kenya and the impacts on nomadic pastoralists is a good example.
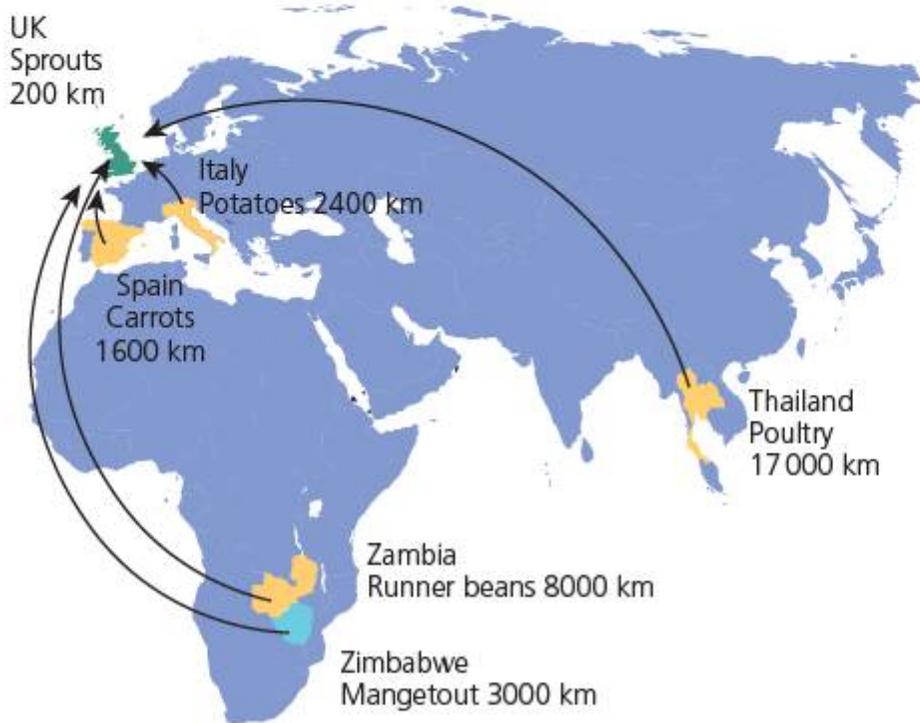
The wastefulness of a Christmas dinner

Figure 3.18 The wastefulness of a Christmas dinner – the ingredients of a traditional Christmas meal bought from a supermarket may have cumulatively travelled 24 000 miles

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■ **QUICK CHECK QUESTIONS**

41 Outline **one** way in which modern commercial farming has affected traditional subsistence-type farming.

42 How many food miles might a traditional Christmas meal account for?

EXAM PRACTICE

14 Discuss the energy efficiency of terrestrial and aquatic food production systems.   [3]

15 Explain the relationships between population growth, social systems and food production technologies. Refer to **named** contrasting countries in your answer.   [9]

Water resources

Revised ☐

The Earth's water budget

Revised ☐

The world's water balance is driven by the Sun. This allows the constant recycling of water between the oceans, the atmosphere and the land. This movement of water between these three reservoirs (storages) is known as the 'hydrological cycle' or water cycle.

■ The oceans play a vital role in the hydrological cycle: 74% of the total precipitation falls over the oceans and 84% of the total evaporation comes from the oceans.

■ Only a small fraction (2.5% by volume) of the Earth's water supply is freshwater.

■ Of this, over 87% is in the form of ice caps and glaciers, 12% is groundwater and the rest is made up of lakes, soil water, atmospheric water vapour, rivers and biota, in decreasing order of storage size.

■ At a local scale the cycle has two main inputs – solar energy and precipitation (PPT) – and two major losses (outputs) – evapotranspiration (EVT) and runoff. A third output, leakage, can also occur from the deeper subsurface to other basins.

Common mistake

Not all freshwater is accessible or replenishable. Only freshwater lakes and rivers are renewable. Many groundwater reserves, such as those under the Sahara, are essentially non-renewable.
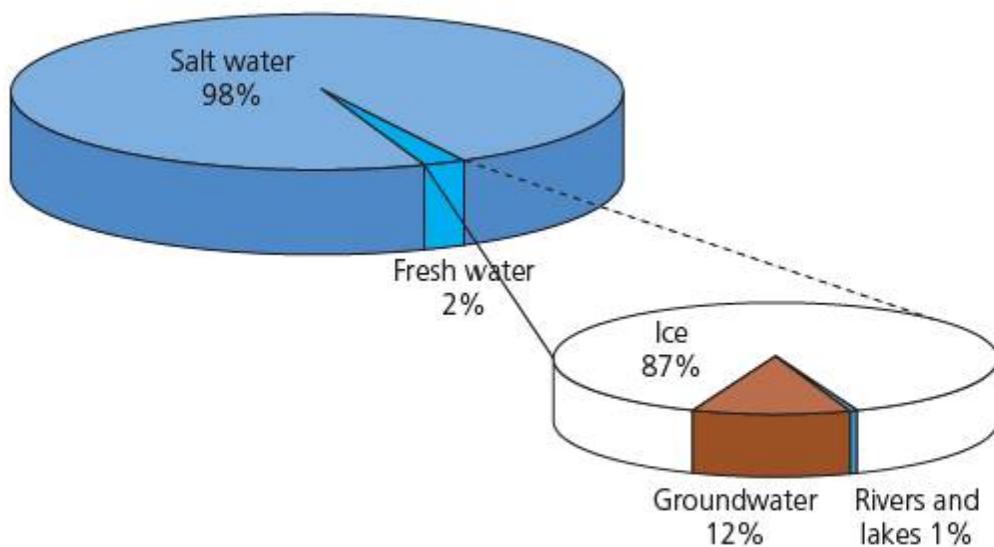
Figure 3.19 Freshwater sources

■ **QUICK CHECK QUESTION**

43 What proportion of the Earth's fresh water is found in **a)** groundwater and **b)** lakes and rivers?

The sustainability of freshwater resource usage

Revised ☐

- Agriculture (irrigation), industrialisation and population increase all make demands on supplies of fresh water.
- Global warming might disrupt rainfall patterns and water supplies in some places and increase rainfall elsewhere.
- The hydrological cycle supplies humans with fresh water but we are drawing water from underground aquifers and polluting it at a greater rate than it can be replenished.
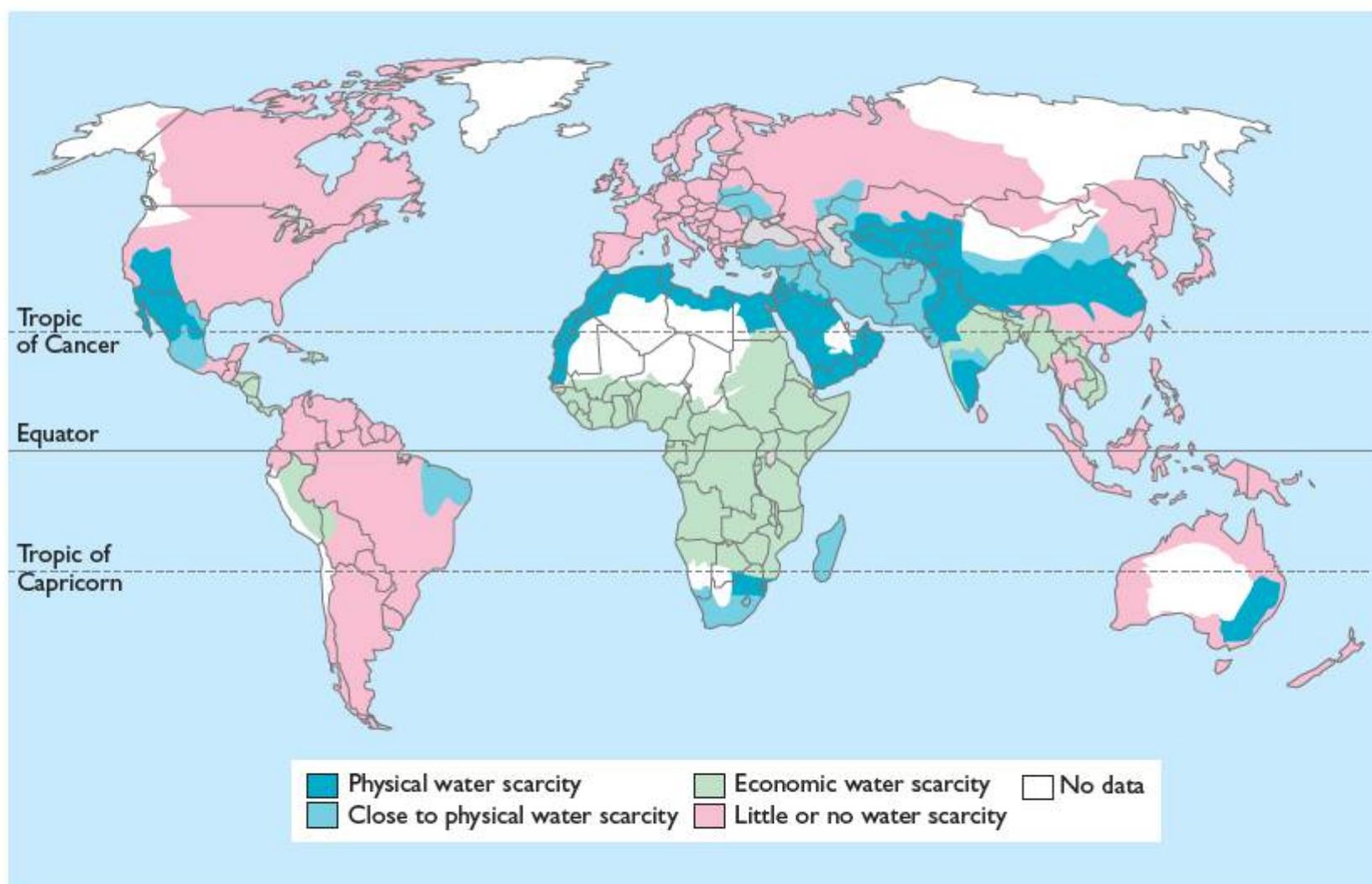

Figure 3.20 Areas of physical and economic water scarcity

44 Suggest **two** reasons why freshwater supplies might be insufficient to meet the demands of human societies in the future.

EXAM PRACTICE

16 Figure 3.20 shows the global distribution of physical and economic water scarcity (shortage).

  a Define the term *water scarcity*. [1]

  b Describe the pattern of global water scarcity. [3]

17 Evaluate the relative importance of factors that determine the sustainable use of freshwater resources. Refer to at least **one** case study in your answer. [9]

Limits to growth

Revised ☐

Carrying capacity and local human populations

Revised ☐

By examining carefully the requirements of a given species and the resources available, it might be possible to estimate the **carrying capacity** of that environment for the species. This is problematic in the case of human populations for a number of reasons:

- The range of resources used by humans is usually much greater than for any other species.
- Furthermore, when one resource becomes limiting, humans show great ingenuity in substituting one resource for another, for example plastic for glass, shale gas for coal and oil.
- Resource requirements vary according to lifestyles, which differ over time and from population to population. For example, a Maasai herdsman uses far fewer resources than an urban dweller in a rich country.
- Technological developments give rise to continual changes in the resources required and available for consumption, for example the increase in nuclear power since the 1950s.
- Human populations regularly import resources from outside their immediate environment, which enables them to grow beyond the boundaries set by their local resources and increases their carrying capacity. The import of food (and even cut flowers) from countries such as Kenya and Zimbabwe in Africa into Europe is a good example. China's purchase of land in Ethiopia and Sudan is another. In this case food is grown and exported to China.
- While importing resources in this way increases the carrying capacity for the local population, it has no influence on global carrying capacity.
- All these variables make it practically impossible to make reliable estimates of carrying capacities for human populations.

Certain areas can 'carry' more people than others. For example, areas with warm, wet climates and fertile soils can support large population densities. By contrast, areas that are too hot, too dry, too cold or too wet will be unable to support many people because they cannot produce sufficient food.

However, in the globalised world, with increased trade, it is possible to get goods to cold areas or hot and dry regions, so that these areas can now support a larger resident population through the import of food and water. Examples include Dubai in the Middle East and the research stations in Antarctica.

> **Key word definition**
> **Carrying capacity** is the maximum number of a species or 'load' that can be sustainably supported by a given environment.

> **Common mistake**
> Students commonly confuse carrying capacity with ecological footprints. The carrying capacity is the maximum number of a species (*people*) that can be sustainably supported by a given environment. In contrast, the ecological footprint refers to the *area of land* and water required to support a defined human population at a given standard of living. The measure takes account of the area required to provide all the resources needed by the population, and the assimilation of all wastes.

> **Expert tip**
> Carrying capacities are not static – they can increase or decrease over time. The optimistic point of view is that carrying capacity will be increased through technological improvements (irrigation, fertilisers, GM food, for example). Pessimists state that the Earth is a finite resource that can only sustain a certain level of population.

45 Define the term *carrying capacity*.

46 Explain why it is difficult to give a precise value for a country's carrying capacity for a human population.

Carrying capacity and recycling, reuse and reduction

Human carrying capacity is determined by the rate of resource consumption, the level of pollution and also the extent of recycling, reuse and reduction in the use of resources.

The limits to growth model was developed in the early 1970s. It predicted that the limits to the growth of the human population would be reached by 2100. This is sometimes called a neo-Malthusian view after Thomas Malthus, who suggested in 1798 that the growth of the human population would outstrip the ability of the Earth to provide sufficient food resources for the population. However, it also suggested that it would be possible to change these projections.

The optimistic view was championed by Esther Boserup, whose views have often been summarised by the phrase 'necessity is the mother of invention'. There are a number of ways in which food production, for example, could be increased:

- growing crops in nutrient-enriched water – hydroponics
- use of high-yielding varieties (HYVs) of plants and selective breeding of animals
- greater use of irrigation and fertilisers
- land reclamation – from the sea, draining of wetlands and terracing of steep slopes
- growing crops in greenhouses.

In terms of energy, there has been:

- use of new resources, such as shale gas
- greater development of alternative energy, such as HEP, solar and wind energy
- increased energy conservation – in the home, in public buildings, in industry and in transport.

As awareness of the problem of resource depletion increases, measures are being taken to tackle the issue. On the other hand, as once poorer countries industrialise, for example Korea, China, India and Vietnam, and standards of living rise, there is increased demand for resources, including food, water and energy.
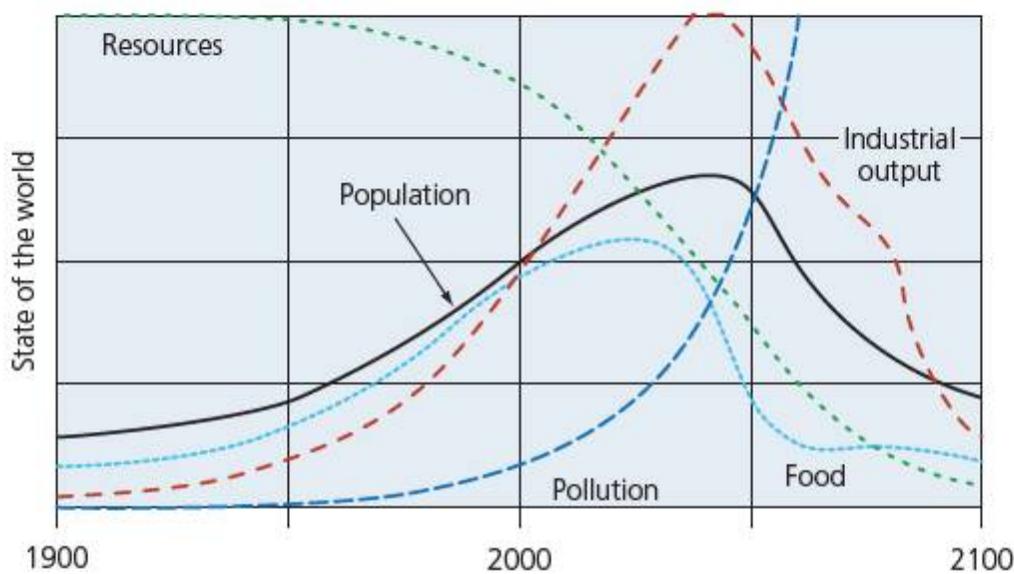
Common mistake

Some students accept the changes suggested by the limits to growth model. Many of these changes might not happen, depending on the choices that people make. With increased recycling and reuse of resources, for example, human carrying capacity can be increased.

Expert tip

The limits to growth model treats the world as a single entity. However, some regions are resource rich, some resource poor. Some areas have rapid population growth, while others have slowed down their growth. Thus, the model is an over-simplification – not all areas of the world will behave as indicated in Figure 3.21.

Figure 3.21 The limits to growth model

■ QUICK CHECK QUESTIONS

47 Describe the population curve shown in Figure 3.21.
48 Comment on the nature of the resources curve shown in Figure 3.21.

EXAM PRACTICE

'Earth provides enough to satisfy every man's need, but not every man's greed.' (Mahatma Gandhi)

'We do not inherit the Earth from our ancestors: we borrow it from our children.' (traditional Kenyan proverb and Native American saying)

18 With reference to the concepts of carrying capacity and environmental value systems, discuss the two quotations above. [7]

19 Justify your response to the claim that the human population has exceeded the Earth's carrying capacity. [7]

Environmental demands of human populations

Ecological footprints

The **ecological footprint** of a population is the area of land, in the same vicinity as the population, that would be required to provide all the population's resources and assimilate its wastes.

The ecological footprint is a useful model for assessing the demands that human populations make on their environment. It consists of eight main categories, as outlined in Table 3.15.

> **Key word definition**
> An **ecological footprint** is the area of land and water required to support a defined human population at a given standard of living. The measure takes account of the area required to provide all the resources needed by the population, and the assimilation of all wastes.

Table 3.15 Categories contributing to the ecological footprint

Land category	Land use category	Land use
Energy land	Land 'appropriated' by fossil fuel energy use	Energy or CO_2 land
Consumed land	Built environment	Degraded land
Currently used land	Gardens	Reversibly built environments
	Crop land	Cultivated systems
	Pasture	Modified systems
	Managed forest	Modified systems
Land of limited availability	Untouched forest	Productive natural ecosystems
	Non-productive areas	Ice caps, deserts

Table 3.16 Advantages and disadvantages of the ecological footprint concept

Advantages	Disadvantages
It is a useful snapshot of the sustainability of a population's lifestyle	It does not include all information on the environmental impacts of human activities
It provides a means for individuals or governments to measure their impact and to identify potential changes in lifestyle	It is only a model so it is a simplification and lacks precision
It is a popular symbol for raising awareness of environmental issues	It uses approximations of actual figures that cannot be accurately calculated
	It does not show the types of resources used – it shows only total resources
	It is negative in approach, so could be perceived as de-motivating

> **Common mistake**
> National ecological footprints hide variations in use. Some people in a society have a very large ecological footprint, whereas others have a small footprint.

> **Expert tip**
> There are different approaches to the study of ecological footprints. For example, ecocentrists suggest that the only way we can reduce our ecological footprint is by working with nature. In contrast, technocentrists believe that we can reduce our ecological footprint with the use of technology.

■ QUICK CHECK QUESTIONS

49 Define the term *ecological footprint*.
50 Identify the eight main categories that are used to assess a society's ecological footprint.

Calculating ecological footprints

Although the accurate calculation of an ecological footprint might be very complex, an approximation can be calculated using per capita food consumption and per capita CO_2 emission in the formulae below:

$$\text{per capita land requirement for food production (ha)} = \frac{\text{per capita food consumption (kg yr}^{-1})}{\text{mean food production per hectare of local arable land (kg ha}^{-1}\text{ yr}^{-1})}$$

$$\text{per capita land requirement for absorbing waste } CO_2 \text{ from fossil fuels (ha)} = \frac{\text{per capita } CO_2 \text{ emission (kg C yr}^{-1})}{\text{net carbon fixation per hectare of local natural vegetation (kg C ha}^{-1}\text{ yr}^{-1})}$$

The total land requirement (ecological footprint) can then be calculated as the sum of these two per capita requirements, multiplied by the total population.

This calculation clearly ignores the land or water required to: provide any aquatic and atmospheric resources; assimilate wastes other than carbon dioxide (CO_2); produce the energy and material subsidies imported to arable land for increasing yields; replace loss of productive land through urbanisation; and so on. However, as a model, it is able to provide a quantitative estimate of human carrying capacity. It is, in fact, the inverse of carrying capacity as it refers to the area required to sustainably support a given population rather than the population that a given area can sustainably support.

Worked example				
	Per capita food (grain) consumption (kg yr^{-1})	Mean food (grain) production per hectare of local arable land (kg ha^{-1} yr^{-1})	Per capita CO_2 emissions (kg C yr^{-1})	Net carbon fixation per hectare (kg C ha^{-1} yr^{-1})
Brazil	210	2919	1900	10000
Canada	710	3031	16900	4000

Brazil's ecological footprint per person is thus (210/2919) + (1900/10000) = 0.072 + 0.19 = 0.26 gha

Canada's ecological footprint per person is (710/3031) + (16900/4000) = 0.23 + 4.25 = 4.45 gha

Note that these are very simplified footprints because they only take into account two categories. The actual ecological footprints for both countries would be much larger.

Figure 3.22 Ecological footprints for selected countries
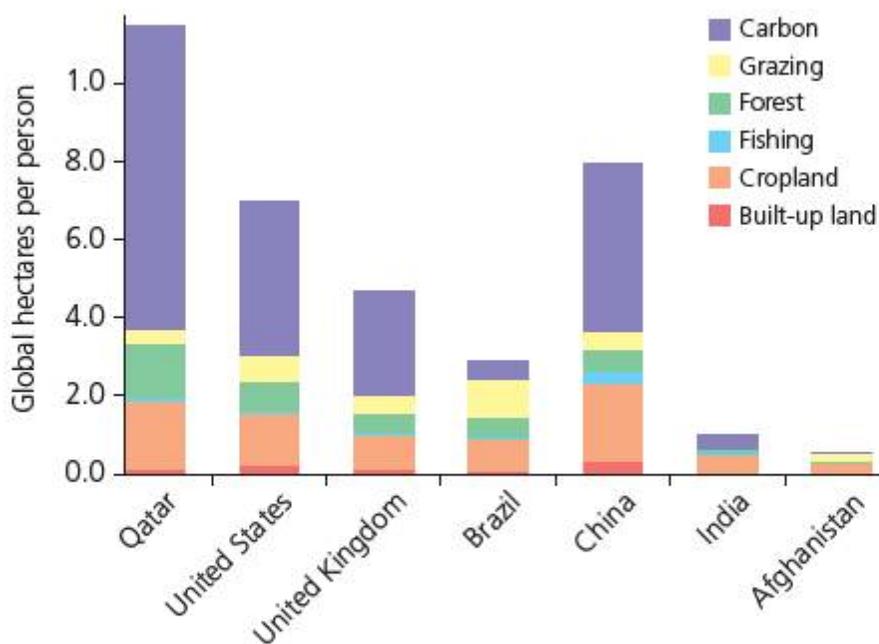
Common mistake

Some students forget to give any units – ecological footprints refer to the size of land/water needed to support a population. The units should be given as hectares (ha) or global hectares (gha).

Expert tip

Be aware of some of the differences in the size of ecological footprint for contrasting countries, as well as differences in the structure (make-up) of the footprint, as shown in Figure 3.22.

Ecological footprints in LEDCs and MEDCs

Revised ☐

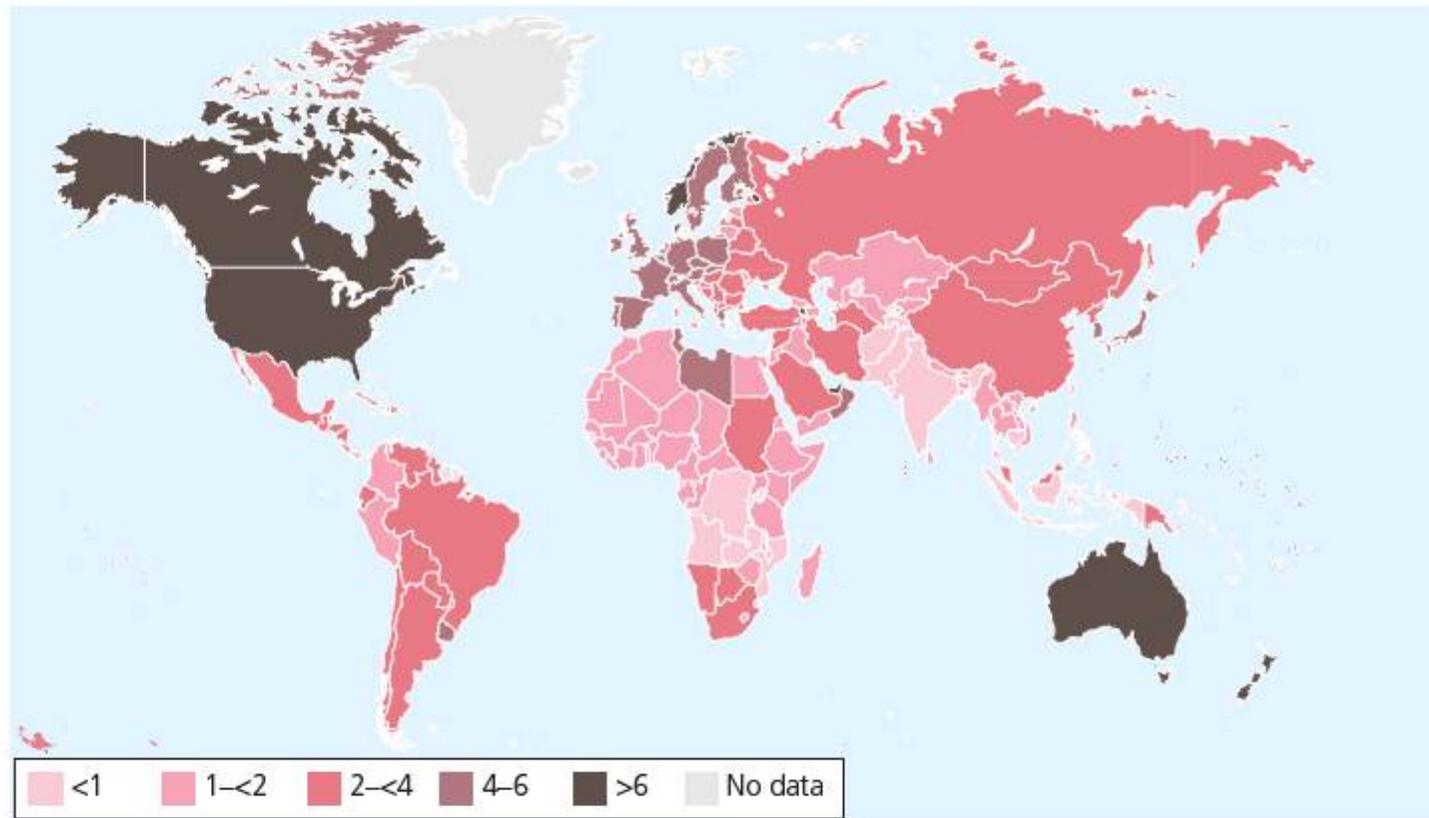

| <1 | 1–<2 | 2–<4 | 4–6 | >6 | No data |

Figure 3.23 Global ecological footprints (global hectares per person)

A number of factors help explain the differences in the ecological footprints of populations in LEDCs and MEDCs.

■ Ecological footprints can be related to stages of the demographic transition model (DTM).
■ Generally there is an increase in the ecological footprint with each stage of the DTM. However, highly developed countries may now be reducing footprints through, for example, energy efficiency strategies.
■ Energy use is much greater in later stages as people have more appliances.
■ Greater wealth leads to higher consumption of goods and natural resources such as water.
■ There is more use of transport/travel by individuals in stages 4 and 5, so more carbon emissions occur.
■ In stages 4 and 5 more goods are imported, so there are more pollutants, food miles and carbon emissions.
■ There is also greater production of domestic waste in stages 4 and 5, so more area is needed to absorb it.
■ Increasing levels of industrialisation from stage 3 onwards lead to more pollutants.
■ Populations more dependent on fossil fuels have higher CO_2 emissions.
■ People in later stages of the DTM tend to eat more meat than those in earlier stages.
■ Data for food consumption are often given in grain equivalents, so that a population with a meat-rich diet would tend to consume a higher grain equivalent than a population that feeds directly on grain.
■ In MEDCs, about twice as much energy in the diet is provided by animal products than in LEDCs.
■ Grain production will be higher with intensive farming strategies.
■ The footprint for a meat eater is likely to be much larger than for a vegetarian because production of meat requires a greater energy input than growing crops.

- Meat eaters are eating at a higher trophic level, which means more land is required to create feed for livestock and for raising livestock.
- Transport of meat for processing increases the footprint size.

Table 3.17 Ecological footprints for China, India, USA and UK

Country	Population	Ecological footprint per person (gha)
China	1.3 billion	1.84
India	1.15 billion	1.06
USA	303 million	12.22
UK	60 million	6.29

■ QUICK CHECK QUESTIONS

53 Describe the main pattern of global ecological footprints as shown in Figure 3.23.
54 Using the data in Table 3.17, work out the total ecological footprint for each of the four countries.

Common mistake

When calculating ecological footprints from data such as those in Table 3.17, don't forget to check whether you are dealing with millions (6 zeros after the number) or billions (nine zeros after the number)! It is easily done!

Expert tip

Different sources produce different estimates of a country's ecological footprint. For example, the data used in Figure 3.22 and Table 3.17 suggest different values for the USA's ecological footprint. However, both suggest that it is large, just as both suggest that India's is small.

National and development policies and cultural influences on human population dynamics and growth

Revised

- Many policy factors influence human population growth. Policies can be described as **pro-natalist** (in favour of more births) or **anti-natalist** (trying to reduce the birth rate). Other policies can indirectly affect the death rate and the birth rate.
- Agricultural development, improved public health and sanitation, and better service infrastructure can stimulate rapid population growth by lowering mortality without significantly affecting fertility.
- Some parents may want large families as they may depend on their children during their old age.
- Following urbanisation, birth rates often fall, as more women have jobs in the **formal** and **informal sectors**.
- Increased awareness about family planning can increase its usage and help reduce the birth rate.
- Cultural or religious influence on contraception usage/non-usage can increase/decrease fertility.
- Boys being more valued than girls in some cultures can increase fertility so that more boys are born.
- Policies that target female education and female participation in the job market are believed to be the most effective method for reducing population pressure.
- Policies can encourage immigration to facilitate gaps in the labour market in countries with falling birth rates.

CASE STUDY

CONTRASTING POPULATION POLICIES IN CHINA AND SINGAPORE

The most famous anti-natalist policy is China's one-child policy. Introduced in 1979, it limits the majority of Chinese families to just one child. Without it, China's population would now be 400 million larger.

Some critics believe that China's fertility would have come down regardless, as a result of urbanisation, industrialisation, improved female education and more working women. Policies directed towards the education of women, enabling women to have greater personal and economic independence, may be the most effective method for reducing population pressure.

Singapore also followed an anti-natalist policy but changed during the 1980s to a pro-natalist policy. Its fertility rate had dropped to below 1.25, and the workforce was decreasing in size. The government offered incentives to families to have three or more children if they could afford them.

Despite the incentives, Singapore's fertility rate has remained low, as women continue to play an active role in the workforce, and are choosing jobs ahead of having children.

Common mistake

Some students state that the one-child policy is the reason for the fall in the birth rate in China. It is just one factor among many – female education, female participation in the workforce, rising material ambitions and industrialisation are also important.

Expert tip

Even if the birth rate falls, there could be an increase in population size. This is known as **population momentum**. This is because of a large proportion of the population entering the reproductive years and is common in countries with a youthful population.

The Millennium Development Goals

In 2000 the United Nations announced its Millennium Development Goals. The aim of the goals is to address issues of poverty, inequality and the environment. Many of them address population growth indirectly, for example:

- MDG 1 Eradicate extreme poverty and hunger
- MDG 3 Promote gender equality and empower women
- MDG 4 Reduce child mortality
- MDG 5 Improve maternal health

■ QUICK CHECK QUESTIONS

55 Briefly explain the meaning of the terms *anti-natalist* and *pro-natalist*.
56 What is believed to be the most effective way to reduce the birth rate?

Population, resource consumption and technological development, and their influence on carrying capacity and material economic growth

As countries develop and improve their standard of living (material economic growth), their use of resources increases. The use of technology reinforces the consumption of resources. For example, in MEDCs and in newly industrialising countries (NICs) such as India and China, the use of cars, computers and electrical goods has increased, thereby increasing the demand for more energy resources. Many believe that the world is reaching its carrying capacity.

The world has been described as a 'globalised consumer culture', in which resources are extracted, manufactured into goods, transported, stored, sold and thrown away, to make way for new goods. The demand for consumer goods has increased dramatically in the last 30 years, putting the world's resources under great pressure.

The role of technology

Because technology plays such a large role in human life, many economists argue that human carrying capacity can be expanded continuously through technological innovation. Like Boserup, the technocrats believe that 'necessity is the mother of invention', and that human flexibility and intelligence will find a solution.

If we learn to use energy and material twice as efficiently, we can double the population or the use of energy without necessarily increasing the impact (load) imposed on the environment. However, many of the 'solutions' e.g. HEP and nuclear energy, require vast amounts of fossil fuels for their construction.

To compensate for foreseeable population growth, improvements in standards of living and the economic growth that is deemed necessary (especially in LEDCs and NICs), it is suggested that efficiency would have to be raised by a factor of 4 to 10 to remain within global carrying capacity.

Many forms of sustainable development, such as sustainable urban development, are very expensive. While it is still cheaper to extract fossil fuels than develop alternative technologies (e.g. hydrogen fuel), governments and oil companies will continue to take the easy options. Governments face many pressures and calls on their resources – investing in technologies that might not be paid back for many decades is not seen as a vote winner.

> **Common mistake**
>
> Reducing population growth does not necessarily lead to lower resource consumption – usually it coincides with increased consumption.

> **Expert tip**
>
> As countries develop, their ecological footprint generally increases, and the need for sustainable forms of development increases. The world could support many more people living at the ecological footprint of the 'average' Indian or Afghan citizen, compared with the 'average' American citizen.

■ QUICK CHECK QUESTIONS

57 Explain the meaning of the phrase *globalised consumer culture*.
58 Briefly explain why increasing standards of living lead to greater resource consumption.

EXAM PRACTICE

20 Explain why some people believe that the ecological footprints of some countries need to be reduced. Justify whether an ecocentric or a technocentric approach to reducing the ecological footprint is more likely to be successful. [9]

21 Discuss how development policies and cultural influences can affect human population dynamics and growth. [8]

Biodiversity in ecosystems

Species, habitat and genetic diversity

In each cell, **DNA** contains the genetic information that codes for the structure and characteristics of an organism. The DNA is divided into sections that code for particular characteristics in a species – these sections are called **genes**.

The term **gene pool** refers to all the different genes in a population. Species with a small gene pool (i.e. low genetic diversity) are more at threat from extinction than those with a larger gene pool. In a large gene pool, it is more likely that alleles exist that will help the species survive any change in their environment. A smaller gene pool means that adaptive genes are less likely to exist and a species is less able to adapt and survive.

> **Key word definitions**
> **Biodiversity** is the amount of biological or living diversity per unit area. It includes the concepts of species diversity, habitat diversity and genetic diversity.
>
> **Species diversity** is the variety of species per unit area. This includes both the number of species present and their relative abundance.
>
> **Habitat diversity** is the range of different habitats or number of ecological niches per unit area in an ecosystem or biome. Conservation of habitat diversity usually leads to the conservation of species and genetic diversity.
>
> **Genetic diversity** is the range of genetic material present in a gene pool or population of a species.

Figure 4.1 Cheetahs have a small gene pool: such species are prone to extinction

Natural selection

Charles Darwin developed the **theory of evolution by natural selection**. This explained how the Earth's biodiversity has arisen:

- Populations show variation.
- Populations always over-reproduce to produce excess offspring.
- Resources, such as food and space, are limited and there are not enough for all offspring.
- There is competition for resources.
- The best adapted survive ('survival of the fittest').
- The individuals that survive contain genes that give them an adaptive advantage.
- These genes are inherited by offspring and passed on to the next generation.
- Over time there is a change in the gene pool, which can lead to the formation of new species.

Speciation is the process by which new species form. Natural selection works with **isolating mechanisms** to produce new species (see page 80).

> **Key word definitions**
> A **species** is a group of organisms that interbreed and are capable of producing fertile offspring.

> **Key word definitions**
> **Isolation** is the process by which two populations become separated by geographical, behavioural, genetic or reproductive factors. If gene flow between the two subpopulations is prevented, new species may evolve. See also **evolution**.
>
> **Speciation** is the process through which new species form. See also **evolution**.

> ■ **QUICK CHECK QUESTIONS**
> 1 Define the term *biodiversity*.
> 2 Explain the difference between *species richness* and *species diversity*.
> 3 Outline the differences between *habitat diversity* and *genetic diversity*.
> 4 Define the term *evolution*.
> 5 Outline the theory of evolution by natural selection.

Common mistakes
Some think that biodiversity is only seen in animals. This is incorrect – it is a term that can be applied to all living organisms.

Don't forget to include 'per unit area' in the definition of *biodiversity*.

Species richness (the number of species) is often used incorrectly as an equivalent term to *species diversity*. Species richness is simply the number of species in an area, whereas species diversity also includes the relative abundance of each species (see page 17).

Figure 4.2 Charles Darwin published the *Origin of Species* in 1859; the book explained and provided evidence for the theory of evolution by natural selection

The role of isolation in forming new species

Revised

Geographical isolation

Geographical isolation is caused by a physical barrier that leads to populations becoming separated, eventually leading to speciation (Figure 4.3). Causes of geographical isolation include plate activity (see page 81), the formation of mountains, seas, lakes, rivers and deserts.
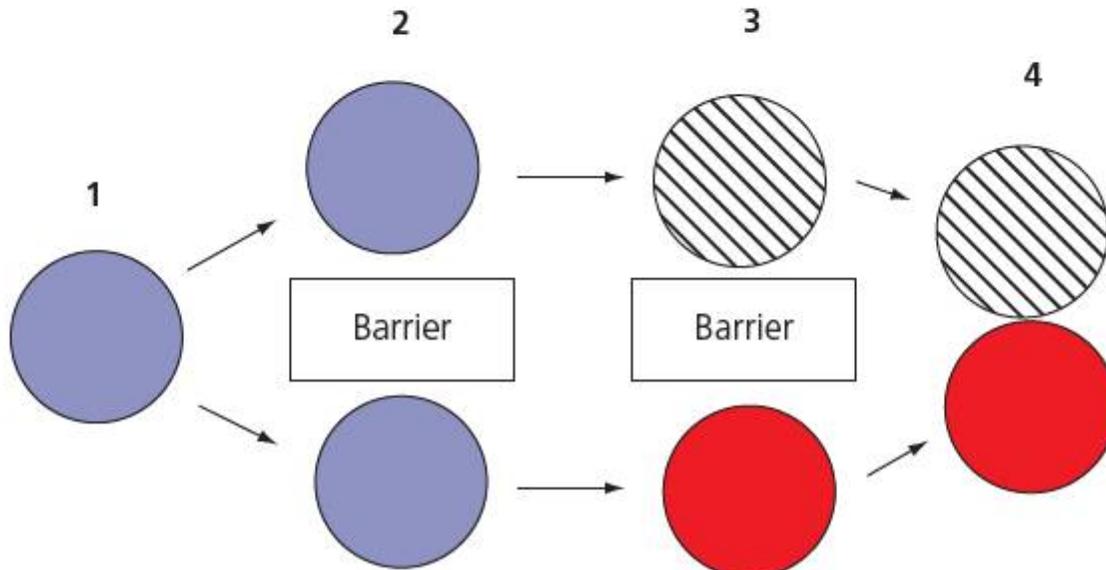

Figure 4.3 The process of speciation: 1 original population; 2 geographical isolation divides the population into two separate groups; 3 populations become adapted to different local conditions and become genetically different from each other; 4 reproductive isolation occurs and the species cannot interbreed if they meet

Reproductive isolation

Reproductive isolation is caused by processes that prevent the members of two different species from producing offspring together. It includes:

- **environmental isolation** – the geographic ranges of two species overlap, but their niches differ enough to cause reproductive isolation
- **temporal isolation** – two species whose ranges overlap have different times of activity
- **behavioural isolation** – courtship rituals (breeding calls, mating dances etc.) between two species vary, such as in birds of paradise
- **mechanical isolation** – physical differences in, for example, reproductive organs prevent mating or pollination
- **gametic isolation** – sperm and ova are incompatible, and will not allow fertilisation to take place.

Plate activity

The outer crust and upper mantle (the **lithosphere**) of the Earth are divided into many plates that move over the molten part of the mantle (**magma**).

- Plates move apart, slide against each other or collide.
- Plates move apart at **constructive plate margins** (Figure 4.4).
- Plates move together at **destructive plate margins** (Figure 4.5).
- Plates collide at **collision plate margins** (Figure 4.6).

> **Key word definition**
> **Plate tectonics** is the movement of the eight major and several minor internally rigid plates of the Earth's lithosphere in relation to each other and to the partially mobile **asthenosphere** below.
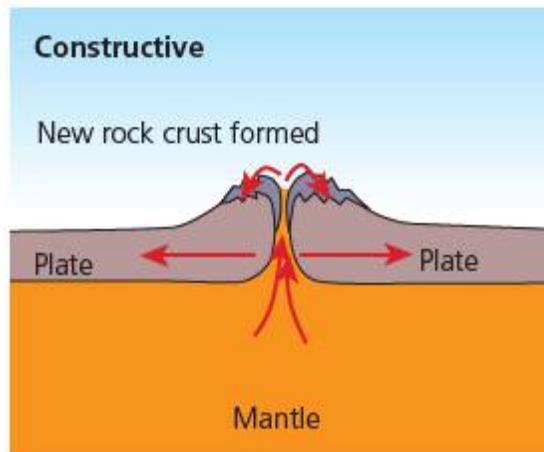
Figure 4.4 A constructive plate margin: continental plates moving apart (e.g. the East African rift valley system, including Lake Tanganyika and Lake Victoria); magma rising from a gap in the crust may create new land (e.g. Iceland)
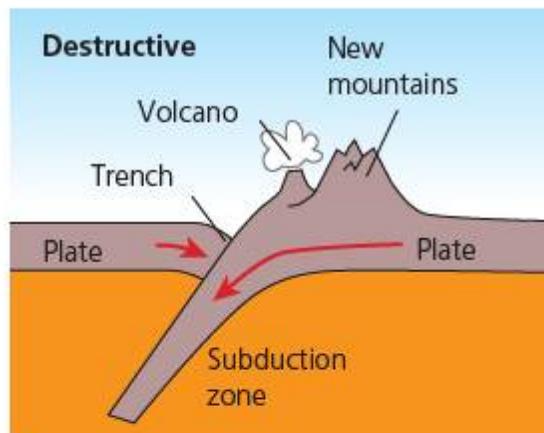
Figure 4.5 A destructive plate margin: crust is subducted beneath (forced under) the other crust, causing rising magma to form new land (e.g. the Andes of South America)
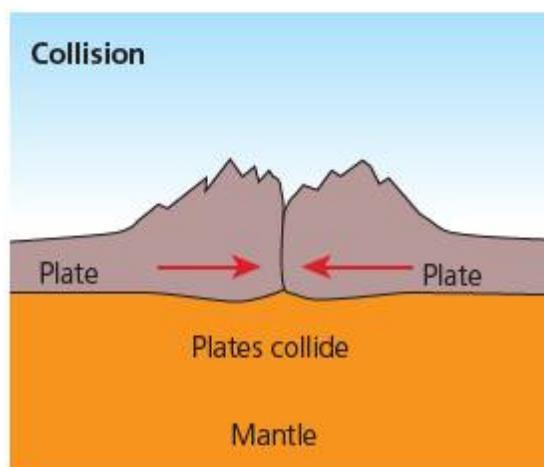
Figure 4.6 A collision plate margin: continental plates collide, leading to increased continental plate thickness and eventually new mountain ranges (e.g. the Himalayas, where the Indian plate is pushed against the Asian plate)

- The separation of continental plates leads to isolation of populations. This separates organisms with a common ancestor. Separation of gene pools results in divergent evolution, for example within the ratites (flightless birds): emu in Australia, ostrich in Africa, rhea in South America.
- Collision of plates can lead to uplift and mountain formation. The mountains form a physical barrier, which isolates populations. The uplift also creates new habitats, promoting biodiversity. Adaptation to new habitats then occurs through natural selection.
- Collision of plates can also cause the spread of species through the creation of land bridges. This leads to a mixing of gene pools and possible hybridisation.
- Plate activity can create new islands, usually through volcanic activity. This can lead to adaptations to fill new habitats/niches – see, for example, the case study on page 82.
- The movement of plates to new climate regions leads to evolutionary change to adapt to new conditions, for example the northwards movement of the Australian plate.

CASE STUDY

GALÁPAGOS FINCHES

- The Galápagos Islands were created by rising magma from breaks in the crust ('hot spots').
- Volcanic islands were formed as a plate moved over the hot spots.
- An ancestral finch colonised the islands from mainland South America.
- Different populations of the finch became isolated on different islands.
- They adapted to the different conditions found on each island (see Figure 4.7).
- Galápagos finches have undergone speciation to fill many of the niches on these volcanic islands and they now are very different from the original mainland South American finch.
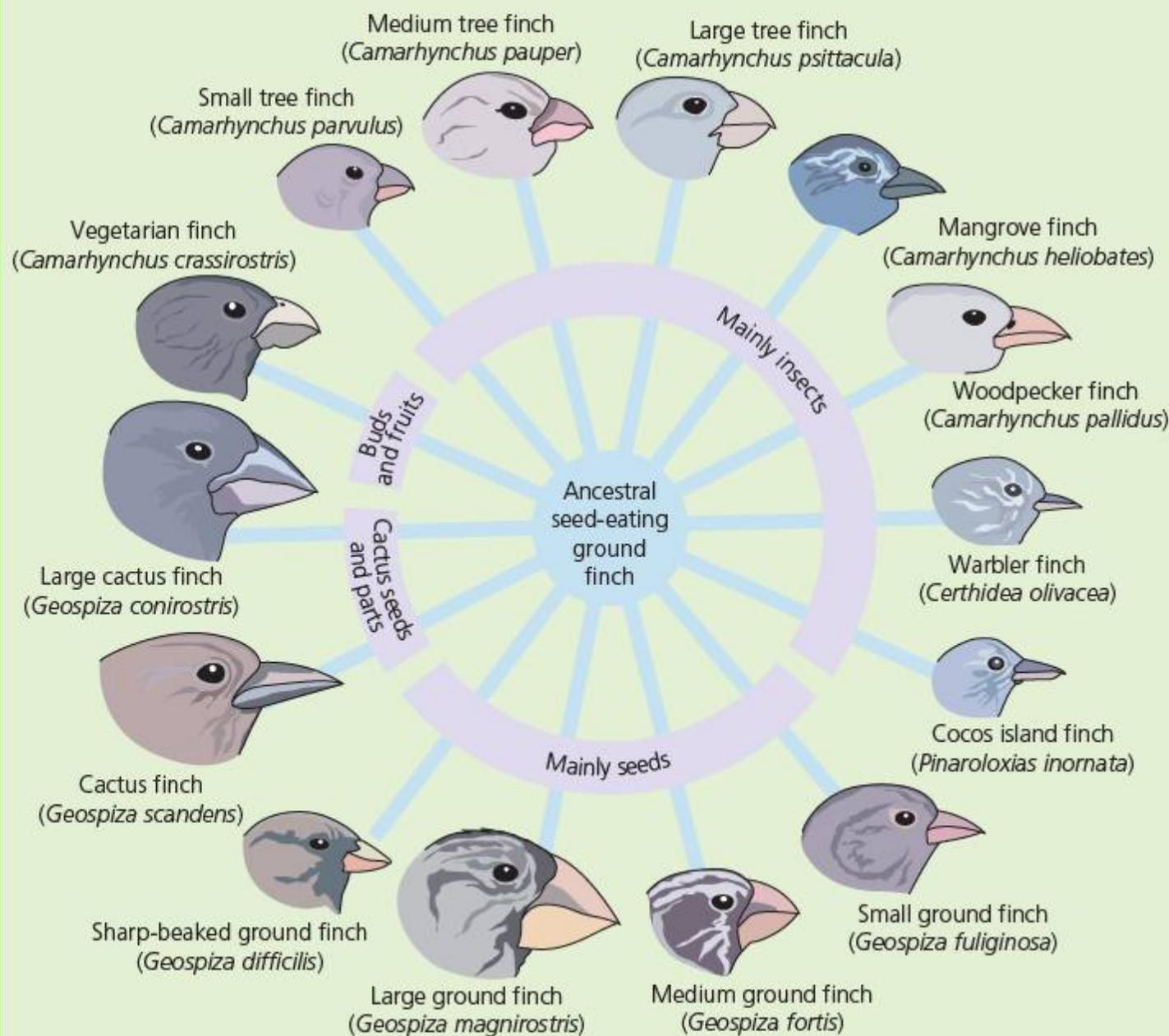
Figure 4.7 Speciation in Galápagos finches; this process is known as **adaptive radiation**

■ QUICK CHECK QUESTIONS

6 Outline how geographical isolation leads to speciation.
7 Explain the role of reproductive isolation in the formation of new species.
8 Outline the role of plate activity in speciation.

Ecosystem stability and succession

Revised ☐

The process of succession

The formation of an ecosystem from, for example, bare rock is called **primary succession**:

- **Pioneer species** arrive (e.g. lichens, mosses, bacteria).
- As pioneers die, soil is created.
- New species of plants arrive that need soil to survive – these displace pioneer species.

- Growth of plants causes changes in the environment (e.g. light, wind, moisture).
- Growth of roots enables soil to be retained; nutrients and water in the soil increase.
- Nitrogen-fixing plants arrive, adding nitrates to soil.
- Soil depth increases further, allowing shrubs and other taller plants to arrive.
- Animal species arrive as species of plant they rely on become established.
- A **climax community** is established.

Succession in areas that already have soil is called **secondary succession**. Diversity changes through succession (see pages 30, 32–33):

- Greater habitat diversity leads to greater species and genetic diversity.
- Complex (i.e. climax) ecosystems have a wider variety of nutrient and energy pathways, which provide stability (pages 32–33).

Human activities such as logging, grazing and burning modify succession (see pages 32–33). They often simplify ecosystems, rendering them unstable – for example, North American wheat farming, a modified system, compared with tall grass prairie, a climax community.

An ecosystem's capacity to survive change may depend on **diversity**, **resilience** and **inertia**.

- Diversity is the number and relative abundance of species present (see pages 17–18).
- Inertia (or persistence) is the resistance of an ecosystem to being altered.
- Resilience is the ability of an ecosystem to recover after disturbance.

> **Key word definition**
> **Succession** is the orderly process of change *over time* in a community. Changes in the community of organisms frequently cause changes in the physical environment that allow another community to become established and replace the former through competition. Often, but not inevitably, the later communities in such a sequence or **sere** are more complex than those that appear earlier.

> **Key word definition**
> A **climax community** is a community of organisms that is more or less stable, and that is in equilibrium with natural environmental conditions such as climate. It is the end point of ecological succession.

Worked example

Using the terms *diversity*, *inertia* and *resilience*, describe the effects of disturbance on tropical rainforest. Compare the effects with one other contrasting ecosystem.

- Tropical rainforests have high diversity and inertia, but if they undergo large-scale disturbance through logging or fires they have low resilience (i.e. take a long time to recover).
- Complex ecosystems such as rainforests have complex food webs that provide high inertia: if one part of a food web is lost other organisms are likely to be there to replace it.
- They also contain long-lived species and dormant seeds and seedlings that promote inertia.
- Rainforests have low resilience because they have thin, low-nutrient soils. Nutrients are locked-up in decomposing plant matter on the surface and in rapidly growing plants within the forest, so when the forest is disturbed, nutrients are quickly lost when the leaf layer and top soil are washed away.
- Grasslands have low diversity and low inertia (i.e. they burn very easily) but are very resilient, because they have nutrient-rich soils, which can promote new growth.

■ QUICK CHECK QUESTIONS

9 Describe the process of succession.
10 Distinguish between *primary* and *secondary succession*.
11 An ecosystem's capacity to survive change may depend on diversity, resilience and inertia. Define the terms *diversity*, *resilience* and *inertia*.
12 Explain how disturbance will affect diversity, resilience and inertia in a **named** ecosystem.

EXAM PRACTICE

1 a Define the term *species diversity*.   [1]

   b Explain how natural selection can produce new species.   [2]

2 State, giving examples, **two** ways in which an understanding of
   plate tectonics has helped to explain patterns of biodiversity.   [4]

3 Explain the relationship between succession and stability.   [6]

4 a Define the term *succession*.   [1]

   b Explain how diversity changes through a succession.   [5]

   c Using the terms *diversity, inertia* and *resilience*, outline the effects
      of disturbance on a **named** ecosystem.   [6]

Evaluating biodiversity and vulnerability

Revised ☐

Factors that lead to loss of diversity

Revised ☐

Natural events can cause a loss of diversity. Examples include:

- volcanic activity
- drought/floods
- ice ages
- meteor impacts.

Human actions can cause a loss of diversity. Examples include:

- agricultural practices such as **monoculture** (a crop of only one species), use of **pesticides** and use of **genetically modified species**
- habitat degradation, fragmentation and loss
- introduction of non-native (**invasive**) species
- pollution
- population growth, leading to disturbance of habitats, pollution, etc.
- **overhunting**, collecting and harvesting.

The rate of biodiversity loss will vary from country to country depending on:

- the ecosystems present
- the protection policies and monitoring systems in place
- environmental viewpoints of the local residents
- the stage of economic development (i.e. LEDC or MEDC).

> **Expert tip**
>
> A way of remembering the human causes of biodiversity loss is the mnemonic *A HIPPO*: **A**griculture, **H**abitat loss, **I**nvasive species, **P**ollution, **P**opulation (i.e. the effects of population growth) and **O**verhunting.

■ **QUICK CHECK QUESTIONS**

13 List **three** natural causes of biodiversity loss.

14 List **six** human causes of biodiversity loss.

15 Outline how agricultural practices have led to a loss of biodiversity.

Vulnerability of tropical rainforests

Revised ☐

Tropical rainforests cover only 5.9% of the Earth's land surface but may contain up to 50% of all species. They are found in South America, Africa and Southeast Asia.

The climate is warm and stable:

- Temperatures vary from 20°C at night to 35°C at midday.
- Rainfall is high, with up to 2500 mm per year.

The constant warm temperatures, high insolation and high rainfall lead to high levels of photosynthesis and high productivity (NPP – see page 26):

- High productivity leads to high biomass.
- This leads to ecosystem complexity, abundant resources (e.g. food) and niche diversity.

- Abundant niches lead to high species richness.
- Biodiversity is therefore high (rainforests contain **biological hotspots**).

Tropical rainforests are vulnerable to disturbance, with an average of 1.5 hectares (equivalent to a football pitch) lost every 4 seconds. Because they have high biodiversity, many species are affected when they are disturbed. Deforestation and forest degradation are being caused by demands for:

- timber
- land for cattle to provide beef
- soya and biofuels (e.g. oil palm in Southeast Asia).

Tropical rainforests are found on nutrient-poor soils that are thin and easily eroded once forest is cleared. The time taken for rainforest to regenerate depends on the level of disturbance:

- Small-scale disturbance, for example from shifting cultivation (pages 62 and 66), can recover in around 50 years.
- Large areas of cleared land will take longer to grow back (around 4000 years), if at all.
- Areas subject to selective logging methods will regenerate more quickly than areas logged using conventional methods.

Threats to tropical rainforest in the 1970s and 1980s led to the growth of the Green movement. **Green politics** is an ideology that places central importance on ecological and environmental goals, and sustainable development. The Green movement aims to reduce deforestation and increase reforestation.

Past and present rates of species extinction

Revised

The fossil record shows that there have been five periods of mass extinction in the past (see Table 4.1). **Mass extinctions** include events in which 75 per cent of the species on Earth disappear within a geologically short time period, usually between a few hundred thousand to a few million years.

Table 4.1 Past mass extinctions, during which 99% of all species that have ever existed on Earth have been lost

Period	Millions of years ago	Possible cause of mass extinction	Biodiversity loss
Cretaceous–Tertiary	65	Asteroid impact *or* Volcanic activity leading to climate change	16% of marine families 18% of land vertebrate families including dinosaurs **76% of all species**
End Triassic	199–214	Volcanic activity leading to climate change	23% of all families **80% of all species**
Permian–Triassic	251	Comet/asteroid impact *or* Volcanic activity reducing O_2 in sea	57% of all families **96% of all species** (largest mass extinction)
Late Devonian	364	Global cooling (followed by global warming), linked to diversification of land plants (less CO_2 in atmosphere)	19% of all families **75% of all species**
Ordovician–Silurian	439	Sea-level changes due to glacier formation	27% of all families **86% of all species**

Past mass extinctions have been caused by natural, physical (abiotic) causes. Scientists consider that the Earth is currently undergoing a **sixth mass extinction**, caused by human activities (i.e. biotic causes). The current mass extinction can be divided into two phases:

- Modern humans dispersed to different parts of the world, around 100 000 years ago.
- Humans started to grow food using agriculture, around 10 000 years ago.
- Scientists predict that at current rates of extinction the Earth will enter its sixth mass extinction within the next 300–2000 years.

■ **QUICK CHECK QUESTIONS**

16 Define the term *mass extinction*.
17 What is the difference between past mass extinctions and the predicted sixth mass extinction?

Factors that make species prone to extinction

Not all species are equally vulnerable to extinction. Certain animals and plants, through their ecology or behaviour, are more at risk. Factors include:

- small population size, which leads to a reduced gene pool and therefore the species is more prone to disease and inbreeding, and susceptible to environmental change (e.g. Asiatic cheetah)
- limited distribution (e.g. golden lion tamarin monkey – see page 89)
- high degree of specialisation in, for example, dietary needs (e.g. giant panda, which mainly eats bamboo)
- slow reproductive rate, i.e. *K*-selected species with a small number of young (e.g. western lowland gorilla)
- low reproductive potential (e.g. Bicknell's thrush in Canada only has 2000–5000 breeding pairs)
- non-competitive/altruistic behaviour (e.g. the dodo, extinct since the late seventeenth century)
- high trophic level, such as a top carnivore, which can accumulate toxins (e.g. Hawaiian monk seal)
- long migration routes (e.g. Siberian crane)
- complex migration routes (e.g. southern blue fin tuna)
- habitat under threat (e.g. Sumatran tiger – see page 88)
- under human pressure from hunting, collecting, trade etc. (e.g. Sumatran rhino).

Expert tip

Natural factors that lead to a loss of biodiversity operate at two different orders of magnitude:

- Extinction at a local level (**background extinction**) caused by, for example, droughts, floods, habitat loss, disease, the evolution of a superior competitor.
- **Mass extinctions** caused by global catastrophic events, for example volcanic activity, meteor impact and glacial events causing changes in sea level.

Common mistake

If an exam question asks you to outline factors that make a species prone to extinction use examples such as those given here: do not talk about general causes for the loss of biodiversity, for example floods, droughts and volcanic activity.

Determining a species' Red List conservation status

The **International Union for Conservation of Nature (IUCN)** has worked for more than four decades to assess the conservation status of species on a global scale. The IUCN presents this information in the **Red List**. This is done to:

- highlight species threatened with extinction
- promote conservation of threatened species.

Different factors are used to determine a species' conservation status. A sliding scale operates, from *least concern* to *extinct*. Factors include:

- population size
- reduction in population size
- numbers of mature individuals
- geographic range and degree of fragmentation
- quality of habitat
- area of occupancy
- degree of endemicity (i.e. only found in one specific area)
- probability of extinction.

Expert tip

The Red List classification system has several different conservation status categories. You do not need to know the definitions of these.

Common mistake

If you are asked to give factors that are used to determine a species' Red List conservation status, do not talk about human activities such as logging: even though such activities mean that some species are more vulnerable than others, it is not a factor that determines Red List status.

■ **QUICK CHECK QUESTIONS**

18 State **three** characteristics that might make an organism vulnerable to extinction.
19 Distinguish between the terms *background extinction* and *mass extinction*.
20 State the role of the IUCN Red List.
21 Outline the factors that are used to determine Red List conservation status.

Extinct, critically endangered and back from the brink

CASE STUDY

THE ELEPHANT BIRD OF MADAGASCAR

Figure 4.8 An elephant bird egg compared with a chicken egg

Table 4.2 Extinction of the elephant bird

SPECIES	Elephant bird
CONSERVATION STATUS	Extinct
THREATS TO SPECIES	Endemic to the island of Madagascar and therefore, once lost there, it was lost globally. Humans arrived on the island from Southeast Asia, which led to the extinction of the giant bird around 1000 years ago: ■ The forest the species relied on for survival was cleared and burnt. ■ Around 80% of the original natural vegetation was lost. ■ The habitat was cleared to create land for farming (rice and grazing land for cattle). ■ The surviving forest did not have enough vegetation to support the giant bird, or it included vegetation of the wrong sort (e.g. Baobab trees). ■ The elephant bird's nutritious eggs were eaten by humans (one egg ≈ 140 chicken eggs – the largest egg of any species that has existed).
ECOLOGICAL ROLE	Herbivore
EFFECTS ON ECOSYSTEM WHEN THE SPECIES DISAPPEARED	Spiny seeds of the endemic plant *Uncarina* were dispersed on the feet of the elephant bird. The loss of the elephant bird would have affected the dispersal of the plant, although domestic animals introduced to the island may now help to disperse the seeds. The forest coconut is a critically endangered endemic species that may have been adapted for passage through the elephant bird gut – the current poor dispersion of this species may have resulted from the extinction of the elephant bird. The species was the heaviest bird that has existed (around 0.5 tonne) and would have eaten large amounts of vegetation, for example in the spiny forest to the south of the island. The loss of the species would have left more vegetation for other species such as Sifaka lemurs.

CASE STUDY

THE SUMATRAN TIGER

Figure 4.9 A Sumatran tiger

Table 4.3 The Sumatran tiger – a species currently critically endangered and heading towards extinction

SPECIES	Sumatran tiger
CONSERVATION STATUS	Critically endangered
THREATS TO SPECIES	Has a small and declining population for the following reasons: ■ Loss of habitat (tropical rainforest). ■ It is seen as a danger to humans and livestock and so is hunted. ■ Fragmentation of its habitat makes breeding difficult. ■ The high market value of its body parts encourages poaching. ■ As a top predator its population is small because little energy reaches the top of the pyramid. ■ The species is only found on one island (Sumatra) and so it is prone to extinction. ■ A large area is needed to maintain a viable population, but tropical rainforest on the island of Sumatra is rapidly being cut down. ■ The small population size leads to low genetic diversity, which leaves the species more prone to disease.
ECOLOGICAL ROLE	Top carnivore
POSSIBLE EFFECTS ON ECOSYSTEM IF THE SPECIES DISAPPEARED	Species at the trophic level below would become more numerous. The shortened food chain produces imbalances at other trophic levels. Sick or weak animals lower down the food chain, usually eaten by this species, are no longer killed. Less fit individuals lower down the food chain survive to breed. Decomposer organisms associated with the tiger's dung are lost.

CASE STUDY

THE GOLDEN LION TAMARIN MONKEY

Figure 4.10 A golden lion tamarin monkey

Table 4.4 The golden lion tamarin monkey – a species currently critically endangered but whose conservation status has been improved by intervention

SPECIES	Golden lion tamarin
CONSERVATION STATUS	Critically endangered, but conservation status has been improved by intervention
THREATS TO SPECIES	90% of their original forest habitat (tropical rainforest) in Brazil has been cut down. The remaining habitat is small and fragmented. The species is only found in one small area of Brazil, and is therefore especially prone to extinction. Thought by some people to be carriers of human diseases such as yellow fever and malaria, and were killed for this reason. Kept as pets as part of exotic pet trade.
ECOLOGICAL ROLE	Omnivore
POSSIBLE EFFECTS ON ECOSYSTEM IF THE SPECIES DISAPPEARED	The golden lion tamarin eats fruits, insects and small lizards. Loss of the species would mean the following: ■ Seed dispersal of plants that have fruits eaten by the monkey would be affected. ■ Species at lower trophic levels, such as insects and small lizards, would become more numerous. ■ Species at higher trophic levels would become less numerous. ■ Shortened food chains would produce changes in other trophic levels and produce imbalances in the forest food web.
HOW ARE THEY BEING RESTORED?	Numbers in the wild have increased from a low of 400 in the 1970s to around 1000 today. Captive breeding programmes in zoos (**ex situ conservation**) have produced numbers that allow release into the wild. There are efforts to preserve native forests for **in situ conservation**, for example Reserva Biologica de Poyo das Antas, near Rio de Janeiro.

Natural area of biological significance under threat

CASE STUDY

BORNEO'S RAINFOREST

Table 4.5 The threats faced by Borneo's rainforest

ECOSYSTEM	Borneo tropical rainforest
DESCRIPTION	■ Borneo is the third largest island in the world and has historically been covered by tropical rainforest. ■ Rainforest is dominated by dipterocarp trees – long-lived, tall, hardwood trees that are valuable timber species. ■ The island has high species diversity, with 15000 plant species, 220 mammal species and 420 bird species. ■ Around 20% of the mammal species are endemic to Borneo. ■ 300 species of tree can be found in 1 hectare of forest. ■ Many species are on the Red List – for example orang-utan, sun bear, Asian elephant and Sumatran rhino.
NATURAL THREATS	■ Natural forest fires ■ Drought ■ Dry periods (El Niño) are caused by the Southern Oscillation, where surface air pressure and ocean temperatures fluctuate between the eastern and western tropical Pacific, causing drier periods in one location and wetter in the other. ■ El Niño contributed to widespread fires in 1982–1983 and 1997–1998. ■ Borneo lies south of the Pacific hurricane belt and so is not subject to these very high winds, although tropical storms can cause canopy or emergent trees to fall, with many neighbouring trees, attached by lianas, being brought down with them.
HUMAN THREATS	■ The rainforest has been commercially logged since the 1970s for export markets, with logging accelerating in the 1980s and 1990s. ■ In 1974 forest cover was estimated to be 6.4 million ha (88% of the total land area) whereas only 4.5 million ha remained in 1985 (i.e. a 30% reduction in 11 years). ■ The deforestation rate (2000–2005) was 3.9% per annum. ■ At the peak of logging operations, trees were removed in large numbers (up to 100 $m^3 ha^{-1}$ in volume). ■ Conventional logging methods were not selective and caused damage to the remaining forest. ■ More recently, selective logging (reduced-impact logging – RIL) methods have been used. These cause less damage and allow faster regeneration of forest. ■ Since the 1990s oil palm has been planted on cleared land (see Figure 4.11). ■ One hectare of oil palm yields up to 5000 kilograms of crude palm oil. ■ Most oil palm plantations are owned by the state or by transnational corporations.

Figure 4.11 Oil palm is used as a food (e.g. in margarine, cooking oil, ice cream, ready meals, biscuits and cakes) and is also used in the production of detergents and cosmetics. Oil palm has replaced tropical rainforest over large areas of Borneo

Table 4.5 *(Continued)*	
CONSEQUENCES OF DISTURBANCE	■ Damage to the remaining forest is proportional to the amount of timber removed. ■ Heavily logged forest using conventional methods can remove 94% more timber than in RIL sites. ■ Conventional logging methods can severely damage forest structure, leading to an increase in light-loving, riverine species such as *Macaranga* trees. ■ Changes in forest structure reduce biodiversity. ■ RIL is better at preserving forest structure and biodiversity. ■ Oil palm plantations are monocultures with low species diversity. ■ Oil palm plantations fragment rainforest, block migration routes, and remove habitats for animals. ■ Insecticides and herbicides are used to control insect pests and weeds, and so reduce biodiversity. ■ Animals such as Asian elephants and orang-utans that stray into the plantations can be illegally killed. ■ Without forest cover, soil is eroded, making it difficult/impossible for the original vegetation to regrow. ■ Loss of forest cover causes changes to stream flow and reduces stream diversity. ■ Loss of forest reduces transpiration from leaves, which affects local weather patterns, leading to drier areas more prone to fire. ■ The valuable role that the ecosystem provides, through biodiversity and controlling weather patterns, has been reduced. ■ The role of the rainforest as an economic resource (e.g. though ecotourism) has been reduced.

■ QUICK CHECK QUESTIONS

22 Describe the ecological role of a **named** extinct species and outline the possible consequences of its disappearance.

23 With reference to the case history of a **named** critically endangered species describe the human factors that have led to its conservation status.

24 Describe how the conservation status of a **named** endangered species is being improved by intervention.

25 Describe the case history of a natural area of biological significance that is threatened by human activities.

EXAM PRACTICE

5 Outline **three** reasons why tropical rainforests are vulnerable to habitat destruction. [3]

6 Name a species of plant or animal that has become extinct, and list **two** factors that help to explain why that species became extinct. [2]

7 List **three** characteristics that might make some bird species more prone to extinction than others. [2]

8 Suggest why more extinctions can be expected on islands than on continents. [5]

9 With reference to a **named** ecosystem describe the natural and human threats it faces and discuss the consequences of this disturbance. [10]

Expert tip

You need to be able to describe the ecological, socio-political and economic pressures that have caused, or are causing, the degradation of an area of biological significance, and the consequent threat to biodiversity.

Conservation of biodiversity

Arguments for preserving species and habitats

There are many different arguments for preserving biodiversity. These include:
- **ethical** reasons (e.g. every species has a right to survive; we have a responsibility to safeguard resources for future generations)
- **aesthetic** (i.e. visual) reasons (e.g. provides beauty and inspiration)
- **economic** reasons:
  - ☐ genetic resources for humans (e.g. improved crops)
  - ☐ commercial resources (e.g. new medicines)
  - ☐ ecotourism (which benefits from higher levels of diversity)
- **ecological** reasons:
  - ☐ conserving rare habitats (e.g. endemic species require specific habitats)
  - ☐ ecosystems with high levels of diversity are generally more stable
  - ☐ healthy ecosystems are more likely to provide ecological services (e.g. pollination; flood prevention)
  - ☐ species diversity should be preserved as it can have knock-on effects on the rest of the food chain.

Ecosystems provide a variety of different goods and services:
- **Goods**, for example food, fibre, fuel (peat, wood and non-woody biomass) and water from aquifers, rivers and lakes. Goods can also be from heavily managed ecosystems (intensive farms and fish farms) or from semi-natural ones (such as by hunting and fishing).
- **Support services** – essentials for life, including primary productivity, soil formation and the cycling of nutrients.
- **Regulatory services**, for example pollination, regulation of pests and diseases, climate regulation, flood regulation, water quality regulation and erosion control.
- **Cultural services**, providing opportunities for outdoor recreation, education, spiritual well-being and improvements to human health.

It is easier to give value to some aspects of biodiversity than others. For example commercial (i.e. economic) value can easily be applied to goods such as timber, medicine and food. It is more difficult to give value to such things as ecosystem support services, ecosystem regulatory services, cultural services, and ethical and aesthetic factors.

The role of intergovernmental and non-governmental organisations

- **Non-governmental organisations (NGOs)** are not run by, funded by, or influenced by governments of any country. Examples include Greenpeace and the World Wide Fund for Nature (WWF).
- **Intergovernmental organisations (IGOs)** are established through international agreements. They bring governments together to work to protect the Earth's natural resources. An example is the United Nations Environment Programme (UNEP).

Both governmental organisations and non-governmental organisations are involved in preserving and restoring ecosystems and biodiversity. Each has contrasting roles and activities.

Table 4.6 Contrasting roles and activities of NGOs and IGOs

	NGO	IGO
Speed of response	Rapid: organisations can make their own decisions	Slow: there must be agreement between governments
Use of media	Use film of activities (e.g. chasing whaling boats) to gain media attention	Professional media liaison officers prepare and read written statements
Diplomatic constraints	Unaffected by political considerations Activities can be illegal, although this is discouraged	Many constraints: cannot make decisions without agreement from all parties Disagreements can cause serious constraints
Political influence	Green politics can establish environmental issues as part of the political process	Direct access to the governments of many countries
Enforceability	No direct power: must use public opinion to persuade governments to act	Use international treaties and national or state laws to protect the environment, ecosystems and biodiversity

International conventions on biodiversity

International conventions have shaped attitudes towards sustainability. The **UN Conference on the Human Environment** (Stockholm, 1972) was the first time that the international community met to consider global environment and development needs together. It led to the **Stockholm Declaration**, which played an essential role in setting targets and triggering action at both local and international levels.

In 1992 the UN Rio **Earth Summit** resulted in the **Rio Declaration** and **Agenda 21**:

- The Earth Summit was attended by 172 governments, and set the agenda for the sustainable development of the Earth's resources.
- The Earth Summit led to agreement on two legally binding conventions: the **UN Convention on Biological Diversity (UNCBD)** and the **UN Framework Convention on Climate Change (UNFCCC)**.
- Both the CBD and UNFCCC are governed by the **Conference of the Parties (CoP)**, which meets either annually or biennially to assess the success and future directions of the Convention. For example CoP 11 of the CBD took place in India in 2012, and CoP 18 of the UNFCCC took place in Doha in 2012.
- In 1997 a follow-up meeting (Rio +5) took place in New York to assess the succession of the Earth Summit and future directions. A number of gaps were identified, for example in social equity and poverty.
- Ten years after Rio, the **Johannesburg World Summit on Sustainable Development** addressed mainly social issues, with targets set to reduce poverty and increase access to safe drinking water and sanitation.
- In 2012, Rio +20 took place to mark the 20th anniversary of the Earth Summit. It had three main objectives: to secure political commitment from nations to sustainable development; to assess progress towards internationally agreed commitments (e.g. CO_2 reductions); and to examine new and emerging challenges.

In 1997, the **Kyoto Protocol** built on the Earth Summit's Climate Change Convention. It was developed at a UN meeting in Kyoto, and agreed to reduce greenhouse gas emissions from 1990 levels.

Expert tip

You need to know about recent international conventions on biodiversity, such as those signed at the Rio Earth Summit (1992) and subsequent updates.

The World Conservation Strategy

The **World Conservation Strategy (WCS)** was established in 1980 by the World Conservation Union (IUCN). The IUCN are concerned with the conservation of resources for sustainable economic development. The WCS consisted of three aims:

- maintaining essential life support systems (climate, water cycle, soils) and ecological processes
- preserving genetic diversity
- using species and ecosystems in a sustainable way.

It outlined a series of global priorities for action, while recommending that each country prepare its own national strategy as a developing plan that would take into account the conservation of natural resources for long-term human welfare.

The WCS emphasised the importance of making the users of natural resources become their guardians and recognised that conservation plans can only succeed with the support and understanding of local communities. It focused on specific arguments for preserving biodiversity (i.e. socio-economic, genetic resource and ecological arguments) because:

- these are more universally agreed by people with different environmental viewpoints
- ethical and aesthetic arguments are more difficult to define and can vary between different communities
- these arguments are more scientifically verifiable than ethical or aesthetic arguments
- most influential nations, and those nations involved in drawing up the WCS, attach more value to scientific validity than other arguments.

■ QUICK CHECK QUESTIONS

26 Outline **four** different arguments for preserving biodiversity.
27 Suggest why it is easier to give commercial value to some aspects of biodiversity than others.
28 Compare the roles and activities of governmental organisations and non-governmental organisations.

Designing a protected area

`Revised ☐`

Protected areas should aim to preserve the greatest amount of natural habitat within an ecosystem, and therefore maintain the complex ecological interactions that maintain equilibrium and biodiversity. In most countries, protected areas are islands surrounded by areas of disturbance.

Island biogeography theory predicts that smaller islands of habitat will contain fewer species than larger islands. It is therefore inevitable that protected areas will have lost some of the diversity seen in the original undisturbed ecosystem. The principles of island biogeography can be applied to the design of reserves (Figure 4.12).

Table 4.7 Features of protected areas that are better or worse for conservation (see Figure 4.12)

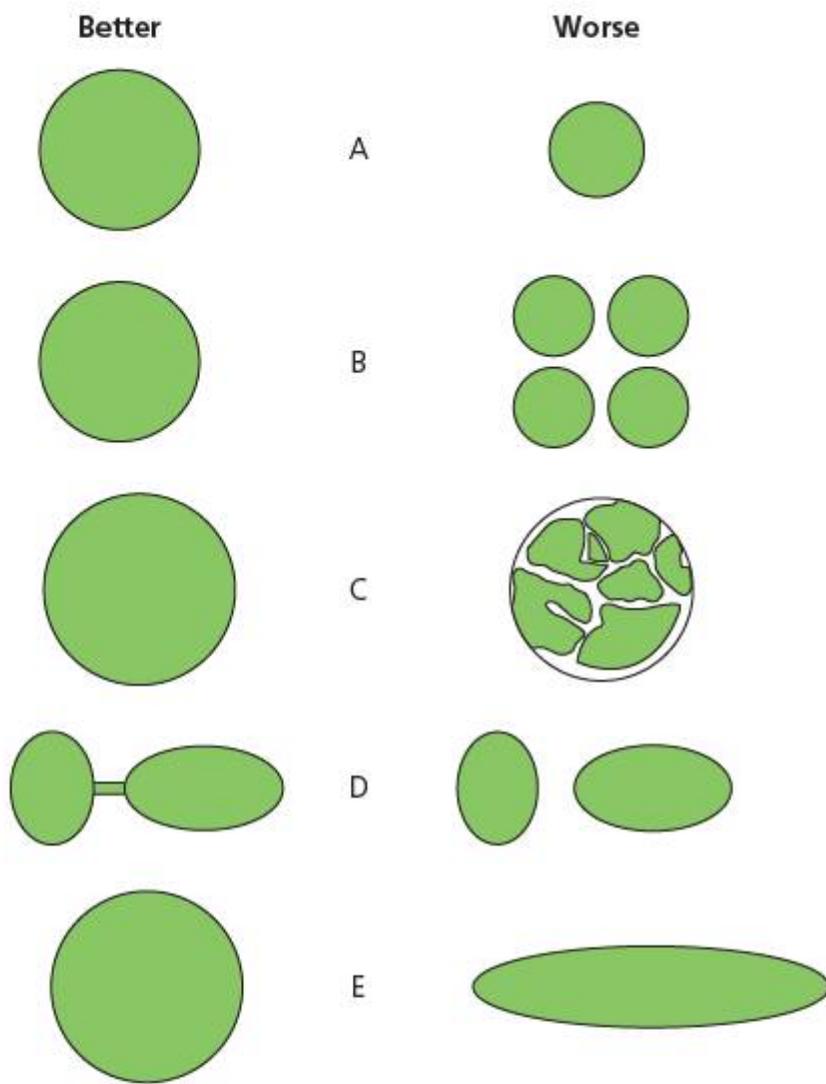|	Better	Worse
A	Single large area	Single small area
B	Single large area	Several small areas of the same total size
C	Intact habitat	Fragmented and disturbed habitat
D	Areas connected by corridors	Separated areas
E	Round (= fewer edge effects)	Not round (= more edge effects)

Figure 4.12 The shape, size and connectivity of reserves is important in designing a protected area

Protected areas that are better for conservation have the following features:

- Larger and so support a greater range of habitats, and therefore greater species diversity.
- Higher population numbers of each species.
- Greater productivity at each trophic level, leading to longer food chains and greater stability.
- Maintain a low perimeter : area ratio to reduce edge effects. Fewer edge effects means more of the area is undisturbed.
- Maintain top carnivores and large mammals by having a large area.
- If areas are divided, then fragmented areas need to be in close proximity to allow animals and plants to move between fragments.
- Maintain gene flow between fragmented reserves by allowing movement along corridors.
- Allow movement of large mammals and top carnivores between fragments by maintaining corridors.

> **Expert tip**
>
> You need to be able to discuss the best design for protected areas using the criteria size, shape, edge effects, corridors and proximity.

Buffer zones

Buffer zones help to protect conservation areas and maintain equilibrium and biodiversity. They contain habitats that are either managed or undisturbed, and minimise disturbance in the protected area from outside influences such as people, agriculture, pests and diseases.

In Figure 4.13, for example, salak palm provides a barrier to stop illegal hunting, encroachment of farmers and illegal felling of trees in the protected area. The salak palm also provides a barrier to stop animals leaving the reserve and being killed in the surrounding area.

The sugar cane is grown by local farmers to provide a cash crop, while fruits from the salak palm also provide food. The crops provide protection against fire.
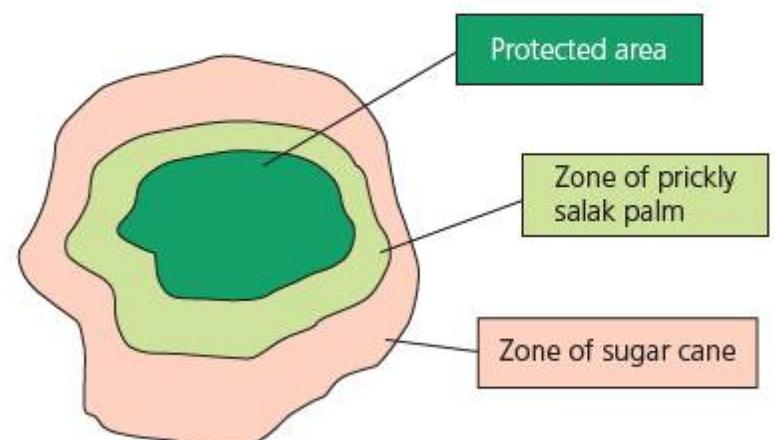
Figure 4.13 Buffer zones around protected forest in Borneo

Evaluating the success of a protected area

Successful protected areas have the following characteristics:
- Provide vital habitat for indigenous species. This can include habitat and food for migrating species such as birds.
- Create community support for the area.
- Receive adequate funding and resources.
- Carry out relevant ecological research and monitoring.
- Play an important role in education.
- Protected by legislation.
- Have policing and guarding policies.
- Give the site economic value.

Expert tip

The granting of protected status to a species or ecosystem is no guarantee of protection without community support, adequate funding and proper research. You need to be able to evaluate the success of a specific local protected area.

CASE STUDY

Figure 4.14 **Orang utan at the rehabilitation centre, Sepilok**

THE KABILI-SEPILOK FOREST RESERVE, BORNEO

The Kabili-Sepilok forest reserve is a 4300 ha area of lowland rainforest in Sabah, Malaysian Borneo. The forest is rich in dipterocarp trees (hardwood species) and contains a wealth of natural wildlife, including orang-utan, leaf monkeys and gibbon. The success of the conservation area is due to many different factors:

Local support
- Local guides and rangers earn a living assisting tourists within the park and protect the forest and its biodiversity.
- There are many ecotourism resorts near the reserve run by local people.
- Their economic future and the future of the park are closely linked.
- They have a positive vested interest in the conservation area.
- They have a respect for, and pride in, the reserve.

Government agencies
- The Sabah Wildlife Department and Forestry Department help to manage the reserve.
- The government, through its employees, wildlife agencies, rangers and guides, provides the park with security and infrastructure.
- These government agencies monitor and control visitor numbers and help to protect the reserve.
- They provide resources.
- They liaise with local groups, non-governmental groups and international organisations.

Research
- The Forest Research Centre (FRC) at Sepilok carries out scientific research within the reserve:
  - This allows its ecosystems and biodiversity to be monitored.
  - It allows new information to be discovered.
  - Research identifies new hazards and new goals.
  - The FRC produces information that supports the park's existence and informs management decisions.
  - It helps educate those inside and those outside the park, both nationally and internationally.
- Research is also carried out by the orang-utan rehabilitation centre at the edge of the reserve (see below), which returns captive animals to the wild.

Education
- An orang-utan rehabilitation centre rehabilitates orphaned orang-utans. It is a major international tourist attraction, focusing on public education, research and conservation.
- A Rainforest Discovery Centre (RDC) provides environmental education facilities for students, teachers and overseas tourists.
- The Bornean Sun Bear Conservation Centre (BSBCC) was created to rehabilitate captive sun bears back into the wild. The BSBCC promotes greater awareness of the ecology of the bear and the threats it faces.

A holistic approach to conservation
- Sepilok is an example of a **holistic approach to conservation**: it is not just an area of wildlife protection, but also one where educational activities are encouraged, research takes place, people use it as an area of relaxation and its cultural value is encouraged (e.g. the national importance of the wildlife to Malaysia).
- Protection without considering other factors, for example economics, culture and development, is unlikely to be successful.
- Multiple-use reserves are more popular and easier to fund, and are more sustainable in the long term.

Strengths and weaknesses of the species-based approach to conservation

The **species-based approach to conservation** focuses on vulnerable species and in raising their profile. It attracts attention and therefore funding for conservation, and can successfully preserve species in zoos and botanic gardens. There is a tendency to focus on the conservation of high-profile, charismatic species that catch public attention both nationally and internationally.

Species-based conservation involves the following:

- the Convention on International Trade in Endangered Species (CITES)
- captive breeding and reintroduction programmes
- zoos.

CITES

CITES is the **Convention on the International Trade in Endangered Species (of Wild Fauna and Flora)**. It is an international agreement aimed at preventing trade in endangered species of plants and animals, and therefore:

- reduces demand for trade
- contributes to species conservation.

Under the convention countries agree to monitor trade in threatened species (and their products) at ports and airports. Illegal imports and exports are confiscated, which discourages illegal trade. If trade in whole organisms or parts of organisms can be reduced, pressure on wild populations is reduced.

CITES has helped protect elephants and rhinos by reducing trade in ivory and rhino horn.

Table 4.8 Advantages and disadvantages of CITES

Advantages	Disadvantages
- It is supported by many countries (145). - It lists many species (around 700). - It bans commercialisation of many products and species. - It has proved to be successful for many species, including elephants, rhinos, marine turtles, tigers, parrots and snakes.	- Enforcement is difficult. - Fines are relatively small and may not deter poaching. - Many countries have not signed and so are not subject to the agreement. - Support by some countries is limited and ineffectual. - The treaty favours large, conspicuous, attractive organisms. - Despite the agreement, illegal hunting still occurs, including the poaching of ivory in Africa.

Captive breeding and reintroduction programmes

Captive breeding and **reintroduction programmes** are part of a species-based approach to conservation:

- They are usually done by zoos.
- A small population is obtained from the wild or from other zoos.
- Enclosures for animals are made as similar to the natural habitat as possible.
- Breeding can be assisted through artificial insemination.

Table 4.9 Advantages and disadvantages of captive breeding and reintroduction programmes

Advantages	Disadvantages
- Populations can build up quickly as habitat and food are abundant. - Abundant food and habitat reduces competition. - Allow predators and diseases to be controlled. - Individual animals can be exchanged between collections to prevent inbreeding and to maintain genetic diversity. - Successful examples include the Arabian oryx and golden lion tamarin (see page 89).	- Does not directly conserve the natural habitat diversity of the species. Conservation of habitat should lead to conservation of species. - Not all species breed easily in captivity (e.g. giant pandas). - It is difficult to maintain genetic diversity and so gene pools of species may be small. - Released animals may be easy targets for predators. - Aesthetic values can lead to an imbalance in conservation activity, meaning that popular, charismatic species are conserved (e.g. Madagascan lemurs) while small, less-popular animals may not be part of the conservation programme (e.g. endemic Madagascan hissing cockroaches). - Some countries may have technical or economic difficulties in establishing programmes.

Zoos

Zoos protect species in carefully controlled environments. They are an example of **ex situ conservation**.

Table 4.10 Advantages and disadvantages of zoos

Advantages	Disadvantages
■ They allow education through visits and so the public are more likely to support conservation campaigns. ■ Genetic monitoring can take place. ■ They allow captive breeding and reintroduction programmes (see above). ■ The number of offspring surviving to adulthood is higher, so species numbers increase more rapidly. ■ Studying species in zoos allows a better understanding of these animals, leading to improved management of the species outside zoos. ■ They can be used as an 'ark', preserving a species until its habitats are protected or restored.	■ There are ethical arguments about keeping animals in captivity for profit. ■ If the zoo is not properly managed, poor conditions can lead to psychological and physiological problems with animals. ■ Zoo animals may be unable to adapt back to life in the wild. ■ They can focus on high-profile/charismatic species and so can be less successful at saving 'non-cuddly' species. ■ Saving a species should require preserving the animal's habitat, which also benefits all other species. ■ A species can be artificially preserved in a zoo while its natural habitat is destroyed (e.g. giant panda).

■ **QUICK CHECK QUESTIONS**

29 Describe and explain the criteria needed to design a successful protected area.
30 Evaluate the success of a named protected area.
31 Discuss the strengths and weaknesses of a species-based approach to conservation.

Comparing different approaches to conservation

Table 4.11 Advantages and disadvantages of different approaches to conservation

	Advantages	Disadvantages
CITES	Can protect many species Signed by many countries Treaty works across borders	Not legally binding Difficult to enforce How it is implemented varies from country to country
Protected areas	Can conserve whole ecosystems Allow research and education Preserve many habitats and species Prevent hunting and other disturbance from humans Allow for in situ conservation	Can be very expensive Difficult to manage Subject to outside forces that are difficult to control Difficult to establish in the first place due to political issues/vested interests
Zoos	Allow controlled breeding and maintenance of genetic diversity Allow research Allow for education Effective protection for individuals and species	Have historically preferred popular animals; not necessarily those most at risk Problem of reintroducing zoo animals to wild Ex situ conservation and so do not preserve native habitat of animals Limits freedom of animals

EXAM PRACTICE

10 Outline the arguments for preserving biodiversity.   [6]

11 a   Name one intergovernmental organisation and one non-governmental organisation involved in conservation.   [2]

    b   Compare the roles and activities of these two organisations.   [4]

12 Outline the general principles behind the World Conservation Strategy.   [4]

13 Explain how the shape and size of a protected area can influence its success in protecting the organisms and ecosystems within it.   [4]

14 Describe and evaluate captive breeding and reintroduction programmes as part of a species-based approach to conservation.   [5]

15 Evaluate the strengths and weaknesses of the Convention on International Trade in Endangered Species (CITES).   [4]

16 Name a protected area that you have studied and suggest **five** reasons that might explain why the area was selected for protection.   [5]

Topic 5　Pollution management

Nature of pollution

Pollution

> **Key word definitions**
> **Pollution** is the addition to an environment of a substance or an agent (such as heat) by human activity, at a rate greater than that at which it can be rendered harmless by the environment, and which has an appreciable effect on the organisms within it.

Point-source pollution and non-point-source pollution

> **Key word definitions**
> **Point-source pollution** is the release of pollutants from a single, clearly identifiable site – for example, a factory chimney or the waste disposal pipe of a factory into a river.
>
> **Non-point-source pollution** is the release of pollutants from numerous, widely dispersed origins – for example, gases from the exhaust systems of vehicles.

Point-source pollution is generally more easily managed because its impact is more localised, making it easier to control emission, attribute responsibility and take legal action.

The major sources of pollutants

Table 5.1 Main sources of pollution

Source	Type of pollution	Cause	Effects
Agriculture	Fertilisers, manure, silage	Spreading fertilisers on fields; runoff of manure and silage	Eutrophication
	Pesticides	Spraying crops	Biomagnification and bioaccumulation
	Salination	Irrigation	Accumulation of salts in soils kills plants
Manufacturing industry	Solid waste	Disposal of by-products and waste	Contaminated land, e.g. Lower Lea Valley, London (Olympic Games site, 2012)
	Toxic spills and leaks	Industrial dumping and accidents	Bhopal, India
Domestic waste	Solid domestic waste	Waste in landfill sites	Contamination of groundwater; release of methane
	Sewage	Waste from toilets; disposable nappies	Eutrophication; reduced oxygen in water; disease
Transport	Runoff from roads	Oil leakages, road drainage	Contamination of groundwater, streams and soils
Energy	Sulfur dioxide	Burning coal	Acid precipitation
	Nitrogen oxides	Formed from atmospheric nitrogen in vehicles	Acid rain, petrochemical smog (tropospheric ozone)
	Particulates (PM10s and PM2.5s)	Combustion of fossil fuels	Reduced respiratory and heart function
	Nuclear waste	Radiation leaks	Fukushima-Daiichi, Japan 2011

EXAM PRACTICE

1   Define the term *pollution*, and distinguish between point-source and non-point-source pollution.   [2]

> **Expert tip**
>
> If the pollution is located at a point distant from the possible source of pollution, it is possible that many potential sources could be involved, i.e. non-point-source pollution.

Detection and monitoring of pollution

Revised ☐

Direct methods of monitoring pollution

Revised ☐

Table 5.2 Methods of monitoring pollution

Monitoring of...	Methods
Air pollution – for example, metals including lead and mercury, chemicals such as CO, SOx and NOx	Use of a monitor or probe (although these can be expensive) Use of filter paper or water in a container such as a rain gauge: ■ Weighing the filter paper (or water) before and after collection ■ Taking the material filtered for chemical analysis or weighing
Particulate matter	Pots attached to structures or cards coated with a sticky substance for collecting the particles
Soil pollution is indicated by changes in soil texture, density, infiltration capacity, moisture content, organic content and chemical content	Depth of surface below the original soil level Infiltration rate Organic and moisture content

> **Common mistake**
>
> A pollutant only becomes a pollutant when there is too much. For example, not all fertiliser/manure causes pollution. Fertiliser that is used by plants does not cause pollution. Nor does spreading manure on fields cause pollution – as long as the amount spread is able to be utilised by plants.

> **Expert tip**
>
> It is important to select different locations for sampling and to take measurements at regular intervals.

> **Expert tip**
>
> Sampling can be both spatial (place-based) and temporal (time-based). Any study should include both, as spatial and temporal patterns can affect results, for example distance from a sewage outlet and whether there was any rainfall.

Figure 5.1 Footpath erosion

1 Good vegetation cover and level soil surface. Vegetation keeps the soil together and aerates it. Rainfall is able to percolate into the ground.

2 Trampling compacts the soil. The infiltration rate is reduced and overland runoff increases. Trampling reduces the vegetation cover consequently the soil is neither bound nor aerated.

3 Erosion of the surface accelerates. Gullies may be formed and the bedrock is exposed. Very little vegetation survives.

Original surface
4 The rough irregular stony surface is unattractive to walkers and may even be dangerous. As a result walkers begin to use the vegetated areas at the side of the footpath and the process begins again.

Figure 5.2 Stages in footpath erosion

Monitoring water quality

Water quality can be measured using standard water testing kits. These kits include tests for dissolved oxygen, pH, phosphates, nitrates, chlorides and ammonia. The readings can then be compared with standardised charts, colour charts or tables of known samples. For example, when testing water for nitrates, clean water has less than $5\,mg\,dm^{-3}$, whereas polluted water can contain $5\text{--}15\,mg\,dm^{-3}$ (Table 5.3). It is important to compare different sites, for example upstream and downstream of a sewage outlet or factory.

Common mistake

Water can contain ammonia, nitrates and phosphates and not be polluted – as long as it does not have too much of any of these.

Table 5.3 Typical values of selected indicators for clean water and polluted water

Substance	Clean water	Polluted water
Dissolved oxygen	Healthy, clean water generally has >75% oxygen saturation	Polluted water shows 10–50% oxygen saturation (raw sewage less than 10%)
Phosphate	Clean water contains <5 mg dm⁻³	Polluted water contains 15–20 mg dm⁻³
Nitrate	Clean water contains 4–5 mg dm⁻³	Polluted water contains 5–15 mg dm⁻³
Ammonia	Clean water contains 0.05–0.99 mg dm⁻³	Polluted water contains 1–10 mg dm⁻³ (raw sewage contains 40 mg dm⁻³)

■ **QUICK CHECK QUESTIONS**
3 Identify the main forms of air pollution.
4 Compare the dissolved oxygen content of clean water with that of polluted water.
5 Describe the changes to vegetation and soil that result from footpath erosion.

Biochemical oxygen demand (BOD)

Aerobic organisms use oxygen in respiration. When there are more organisms and faster respiration, more oxygen will be used. Thus the **biochemical oxygen demand** at any point is affected by:

- the number of aerobic organisms
- their rate of respiration.

BOD is an indirect method used to assess pollution levels in water. The presence of an organic pollutant, such as sewage, causes an increase in the population of organisms that feed on and break down the pollutant. Organic pollution causes a high BOD. Certain species, such as bloodworms and *Tubifex* worms, are tolerant of organic pollution and the low oxygen content associated with it. In contrast, mayfly nymphs and stonefly larvae are associated with clean water.

Thermal pollution lowers the dissolved oxygen content of water. This leads to less aerobic respiration, increased anaerobic respiration and increased decomposition.

Key word definition
Biochemical oxygen demand (BOD) is a measure of the amount of dissolved oxygen required to break down the organic material in a given volume of water through aerobic biological activity.

Expert tips
In highly polluted rivers and streams, species diversity is low, although the population of a certain species may be high.

Common mistake
Sewage effluents do not necessarily discharge polluted water. Sometimes the water is treated and clean. If the water is polluted, the level of pollution will depend upon water temperature and how much water is in the stream.
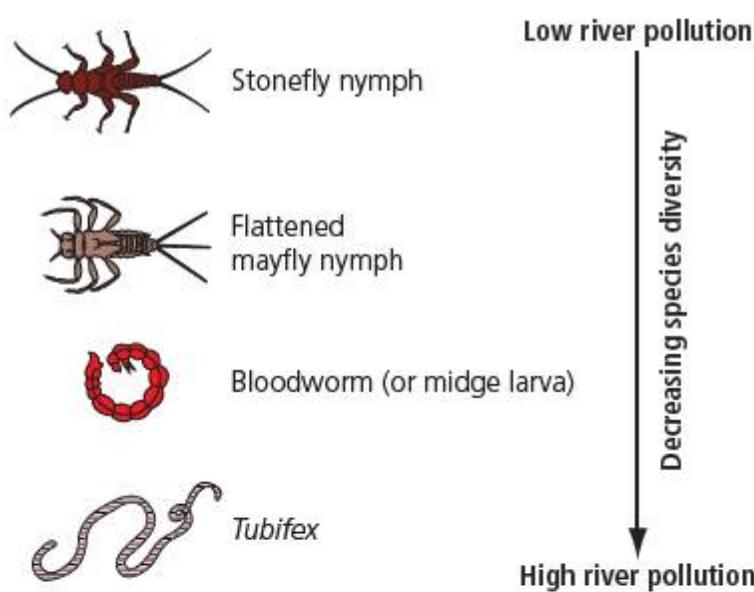
Figure 5.3 Invertebrate indicators of freshwater pollution
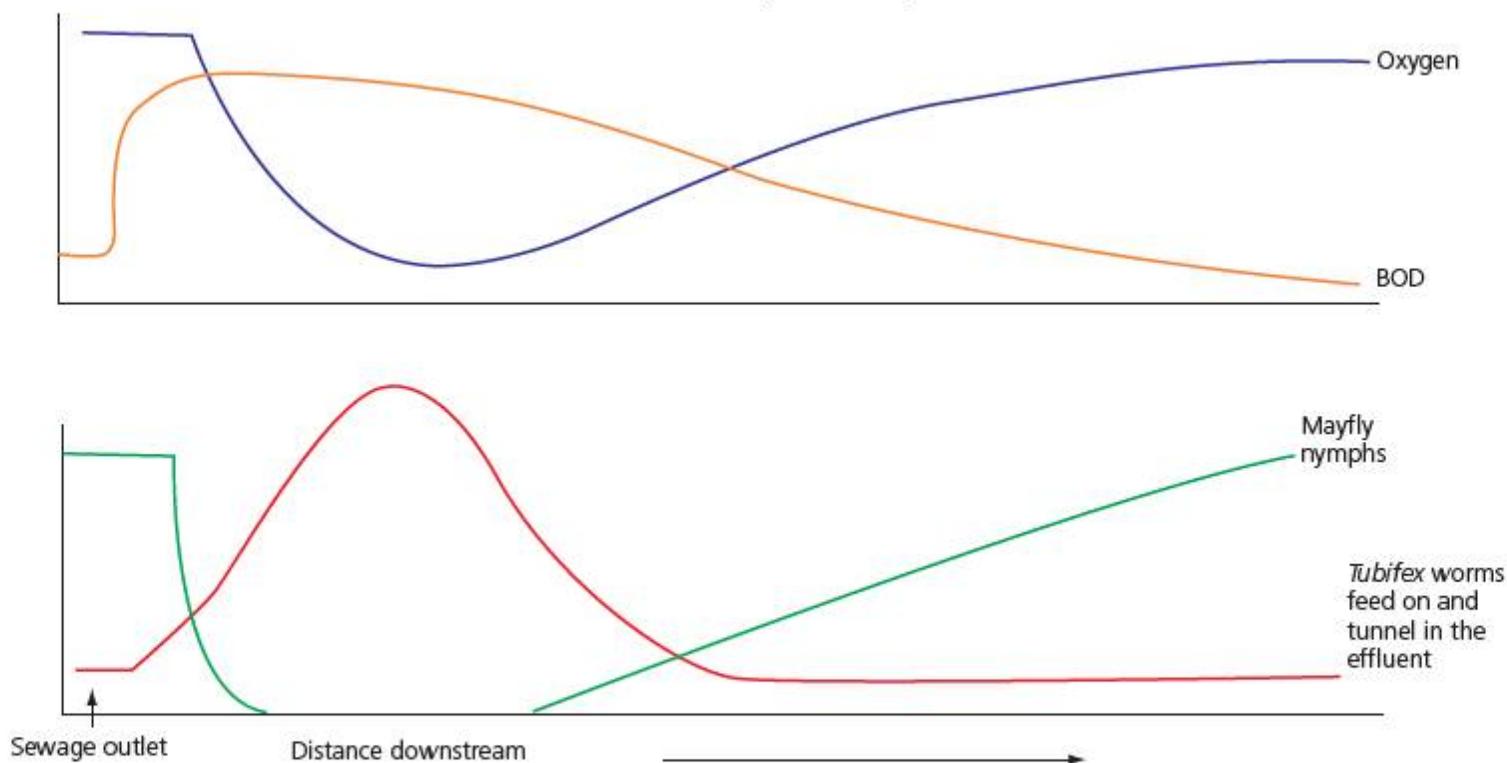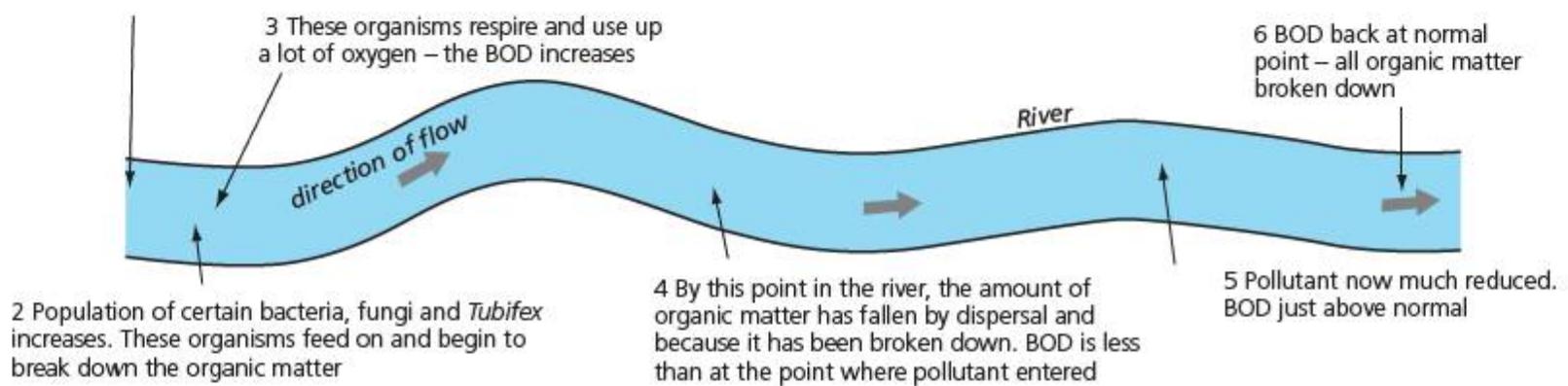
Figure 5.4 Effects of organic pollution

Biotic indices

Revised ☐

Biotic indices can be used as an indirect method of measuring pollution levels. This will involve levels of tolerance, diversity and abundance of organisms.

Indicator species

Certain species have different levels of tolerance to environmental conditions and change. The presence or absence and health of these indicator species can be used to suggest conditions in the environment.

Indicator species can be used as an indirect measure of pollution and/or environmental degradation. Examples include lichens, nettles, red algae and freshwater invertebrates such as *Tubifex* worms, bloodworms and mayfly nymphs.
■ Certain lichen species (such as *Usnea alliculata*) indicate very low levels of sulfur dioxide in the atmosphere.
■ Nettles (*Ullica dioica*) indicate high phosphate levels in the soil.
■ The red alga (*Corallina officinalis*) inhabit saline rock pools and are absent from brackish pools.

Trent biotic index

The Trent biotic index is based on the disappearance of certain indicator species as the levels of pollution increase (Table 5.4). Changes in the amount of light and dissolved oxygen cause less-tolerant species to die out. As pollution increases, diversity decreases. The maximum value for the Trent biotic index is 10.

Table 5.4 Indicator species for the Trent biotic index

Indicator species		Total number of groups present				
		0–1	2–5	6–10	11–15	16+
		Trent biotic index				
Stone fly (Plecoptera) nymph present	More than one species	–	7	8	9	10
	One species only	–	6	7	8	9
Mayfly (Ephemeroptera) nymph present	More than one species	–	6	7	8	9
	One species only	–	5	6	7	8
Caddis fly (Trichoptera) larvae present	More than one species	–	5	6	7	8
	One species only	4	4	5	6	7
Gammarus present	All above species absent	3	4	5	6	7
Shrimps crustacean (*Aseilus*) present	All above species absent	2	3	4	5	6
Tubifex worms and/ or red bloodworm (chironomid) larvae present	All above species absent	1	2	3	4	–
All above types absent	Some organisms (e.g. *Eristalistenax*) not requiring dissolved oxygen may be present	0	1	2	–	–

Human factors that affect the approaches to pollution management

Revised ☐

Cultural values

- Capitalist societies often consider profit over the environmental damage of pollution.
- Often they would rather treat the symptoms (effects) of pollution, when caught, rather than address the causes of pollution.
- Rural society, with its low population density, may have an 'out of sight, out of mind' mentality, with pollution not being a problem if people don't see it or are not adversely affected by it.
- Pollution tolerance levels vary from society to society – some countries accept the waste of other countries for recycling.
- Some types of pollution are more tolerated than others by a particular culture – for example, noise or visual pollution in a rapidly urbanising city is accepted.
- Cultural perspectives can be altered through education.

Political systems

- Less developed countries are often willing to allow pollution to encourage local industry – Mexico's *macquiadoras* industries are a good example.
- The dumping of toxic waste from MEDCs to LEDCs is sometimes allowed by the governments and sometimes it is done illegally – for example in the case of the Dutch company Trafigura and the dumping of toxic waste in Côte d'Ivoire.
- Lower standards for pollution may encourage industry into certain countries. Many footwear companies in LEDCs may have dangerously high levels of glue in the workplace.
- A political blind eye may be turned if the industry is profitable, paying taxes and creating jobs.
- LEDCs often do not have the resources to enforce the laws that they do have in place.

Economic systems

- Many rich countries have a 'throwaway' society and so generate a large amount of waste and pollution.
- Increasingly in the richest countries people value a clean and tidy environment so pollution is not tolerated.
- All three steps of the pollution model are likely to be carried out.
- In many MEDCs the most common step may be the second as the rich society might want to keep the pollution-causing industry, but regulate it.
- Poorer countries often recycle large amounts of waste through informal waste pickers – in Cairo, the Zabbaleen waste collectors recycle up to 80% of the waste they collect.
- Many LEDCs can only afford old, polluting equipment and have limited resources for technology to clean up pollution.
- In some cases UN protocols have not been signed as countries fear they may slow the economy – the USA's failure to sign up to the Kyoto Protocol is a case in point.
- As countries develop there is a tendency to spend more money on pollution prevention.

Expert tips

When discussing the human factors that influence pollution management strategies, real examples should be used.

Common mistake

Although many MEDCs invest in pollution prevention technologies, they still contribute a significant proportion of the world's pollution through travel and transport, and the import of goods produced for their benefit.

The costs and benefits to society of the WHO's ban on the use of DDT

Revised ☐

DDT is a synthetic (man-made) pesticide that has many advantages and disadvantages. During the 1940s and 1950s it was used extensively to control the lice that spread typhus and the mosquitoes that spread malaria. It was also used as a pesticide in farming.

The environmental impact of DDT is based on two processes:

■ **Bioaccumulation** refers to the build-up of non-biodegradable or slowly biodegradable chemicals in the body. DDT gets stored in fat tissues because it is not recognised as a toxin and is not excreted.

■ **Biomagnification** refers to the process whereby the concentration of a chemical substance increases at each trophic level – the end result is that a top predator may have an accumulation that is several thousand times greater than that of a primary producer. An example of the biological effect of DDT is the thinning of eggshells in birds at the top of food chains.

In 2001 the Stockholm Convention on POPs (**persistent organic pollutants**) regulated the use of DDT – it was banned for use in farming but was permitted for disease control.

The plan is to find alternatives for disease control by 2020. In 2006 The World Health Organization (WHO) recommended the use of DDT for regular treatment in buildings in areas with a high incidence of malaria. WHO still aims for a total phase out of the use of DDT.

DDT and the battle against malaria

■ The World Bank estimates that there are about 250 million cases of malaria each year.

■ In South America, cases of malaria increased after countries stopped spraying DDT.

■ Indoor (residual) spraying (IRS) appears to limit the growth of malarial incidence.

■ However, malaria is still on the rise and many people believe that this increase in the disease is unacceptable.

DDT and the ecocentrist viewpoint

■ The ecocentrist position is that ecological laws should drive human decision making.

■ Chemicals such as DDT being added to the environment could harm many species or spread from houses and into the local environment.

■ This affects the right of organisms to remain unmolested – for example, mosquitoes have the right to exist.

■ Ecocentrists argue that alternative (less objectionable) strategies exist such as lowering population density, removing standing water, using natural repellents and encouraging natural predators.

> **Expert tips**
> There are links between DDT and premature births, low birth weight and reduced mental development.

> **Common mistake**
> DDT does not eradicate all mosquitoes – there is evidence of growing resistance to the pesticide. Those that are resistant to DDT will continue to reproduce and spread the resistance.

3 Evaluate the costs and benefits of the use of DDT to society. [6]

Eutrophication

Revised ☐

> **Key word definitions**
> **Eutrophication** is the natural or artificial enrichment of a body of water, particularly with respect to nitrates and phosphates, that results in depletion of oxygen levels in the water. Eutrophication is accelerated by human activities that add detergents, sewage or agricultural fertilisers to bodies of water.

The process of eutrophication

Revised ☐

Figure 5.6 A eutrophic river

Natural and human causes of eutrophication

- There are natural and human causes of **eutrophication**.
- Both result in an increase in nitrates and/or phosphates, leading to rapid growth of algae, accumulation of dead organic matter, a high rate of decomposition and lack of oxygen.
- Natural cycles can include nutrients added from decomposing biomass, runoff from surrounding areas and upwelling ocean currents bringing nutrients to the surface.
- Human causes include runoff of fertilisers or manure from agricultural land. Similarly, domestic waste water may contain phosphates from detergents, and non-treated sewage can also lead to eutrophication.

> **Common mistake**
>
> Eutrophication can be natural as well as human-induced. Human-induced eutrophication happens a lot faster than natural eutrophication and occurs on a larger scale.

> ■ **QUICK CHECK QUESTIONS**
>
> **17** Identify **two** natural causes of eutrophication.
> **18** Identify the **two** main chemicals involved in the process of eutrophication.

Eutrophication and feedback cycles

Table 5.5 Positive and negative feedback in the eutrophication process

Positive feedback occurs in the process of eutrophication	Negative feedback can also occur during the process of eutrophication
■ As more nutrients are added to the system, the biomass of algae increases due to the availability of nutrients. ■ Decomposition of the increased biomass leads to further nutrient load and so further deviation from the long-term equilibrium. ■ Hence positive feedback occurs. ■ The growth of algae block light, so causing underwater plants to die and create more nutrients as they decompose. ■ More nutrients lead to further growth of algae so further deviation from the equilibrium, thus there is increased positive feedback. ■ An increase in bacteria causes increased BOD, hence oxygen-dependent organisms to die. ■ This increase in dissolved organic matter leads to even further increase in BOD/bacteria, so further deviation from equilibrium, reinforcing positive feedback.	■ The increase in nutrients promotes growth of plants that store them in biomass. ■ This leads to a reduction in nutrients, so balance is restored, i.e. negative feedback. ■ The increase in algae will lead to increases in species that feed on algae. ■ This may lead to subsequent decrease in algal populations, so balance is restored. ■ The increase in dead organic matter provides more food for decomposers, which increase in number. ■ Increased rate of decomposition leads to a decrease in dead organic matter, so balance is restored, i.e. negative feedback occurs.

Expert tip

For full credit in describing feedback, responses should identify two steps:

■ Step 1: how change in one factor causes change in another.
■ Step 2: how the second factor affects the first, either increasing its change (positive feedback) or decreasing its change (negative feedback).

The impacts of eutrophication

Revised ☐

Impacts on the ecosystem

■ Both human and natural eutrophication lead to an increase in biomass of algae.
■ The algae lower light penetration to underwater plants.
■ The increased death of algae and underwater plants leads to an increase in DOM as bacteria multiply.
■ More bacteria increase BOD, which leads to lowered oxygen content of water (hypoxia).
■ Reduced oxygen leads to the death of many organisms.
■ Net primary productivity is usually higher compared with unpolluted water, and may be indicated by extensive algal or bacterial blooms.
■ Diversity of primary producers changes and finally decreases; the dominant species change.
■ The length of the food chain decreases as algae lock up the nutrients and block sunlight from reaching the riverbed.
■ However, as eutrophication proceeds, early algal blooms give way to cyanobacteria (blue-green algae).
■ Fish populations are adversely affected by reduced oxygen availability, and the fish community becomes dominated by surface-dwelling coarse fish, such as roach and rudd.
■ With less sunlight penetrating the water macrophytes (submerged aquatic plants) disappear because they are unable to photosynthesise.
■ In theory, the submerged macrophytes could also benefit from increased nutrient availability, but they are shaded by the free-floating microscopic organisms.

Expert tip

Most lakes are naturally oligotrophic (nutrient poor) – once eutrophication starts to occur, productivity increases as nutrient enrichment occurs.

Common mistake

Eutrophication leads to a change in species composition rather than removing all species. Surface-dwelling organisms are favoured rather than bottom-dwelling organisms, with the exception of the bacteria that decompose the dead organic matter.

Impacts on society

Eutrophication has impacts on human populations. One is financial – the loss of fertilisers from fields may reduce crop productivity and therefore farm yield and profit. Moreover, the cost of treating nitrate-enriched water is expensive – in the UK this is estimated to cost between £50 million and £300 million each year.

Nitrate-enriched water is associated with higher rates of stomach cancer and 'blue baby syndrome' (methaemoglobanaemia – insufficient oxygen in pregnant women's blood). However, correlation does not equate with causation and many other factors are likely to be involved.

■ QUICK CHECK QUESTIONS

19 Explain why macrophytes die out as a result of eutrophication.
20 Explain why BOD increases following eutrophication.

Pollution management strategies

Altering human activity

Altering the human activity that produces pollution can include alternative methods of enhancing crop growth, alternative detergents, and so on. For example:

- Avoid spreading fertilisers in winter, as the soil is bare and runoff may wash fertilisers in to rivers and streams.
- Use autumn-sown crops – these maintain a cover during the winter, and may conserve nitrogen in the soil.
- Use less nitrogen if the previous year was dry (more will be left in the soil).
- Use organic fertilisers (manure) on agricultural fields.
- Practise mixed cropping or crop rotation so that less fertiliser is needed.
- Do not apply fertilisers to fields that are next to streams and rivers.

Regulating and reducing pollutants at the point of emission

Ways to regulate and reduce pollutants at the point of emission include the following:

- Use sewage treatment processes that remove nitrates and phosphates from the waste.
- Use zero- or low-phosphorus detergents.
- Only use washing machines with a full load of washing.
- Reduce the use of fertilisers in gardens.

Clean-up and restoration

Clean-up and restoration techniques include the following:

- Pump mud from eutrophic lakes and reintroduce plant and fish species.
- Remove nutrient-rich sediment by pumping.
- Pump air through lakes to avoid the low-oxygen conditions.
- Remove biomass (e.g. water hyacinth or reed) and use it for biofuel or for thatching.
- Reintroduce plant and animal species.
- Use barley bales to lock up nitrates in the water (Figure 5.7).
- Treat with a solution of aluminium or ferrous salt to precipitate phosphates.

> **Common mistake**
>
> Although there are many potential solutions to the problem of eutrophication, it is not always possible to solve it. This is because it is non-point-source pollution and there are many different causes. Moreover, not every country has the resources to implement the strategies.

> **Expert tip**
>
> In some cases the same response can be classified as technocentric or ecocentric. Barley bales are an ecocentric approach (using nature), although the research into the best forms of material to absorb nitrates can be a technocentric approach.

> ■ **QUICK CHECK QUESTIONS**
>
> 21 Explain why fertilisers should not be used in winter.
> 22 What type of pollution management strategy is phosphate stripping?

Figure 5.7 The use of barley bales to lock up nitrates in the water

EXAM PRACTICE

4 Describe and evaluate ecocentric and technocentric responses to eutrophication. [8]

Solid domestic waste

Types of solid domestic waste

There are many types of solid domestic (or municipal) waste (rubbish or garbage). In an MEDC these generally consist of:

- paper/packaging/cardboard (20–30%)
- glass (5–10%)
- metal (less than 5%)
- plastics (5–10%)
- organic waste from kitchen or garden, including waste wood (20–50%)
- textiles (less than 5%)
- nappies (diapers) (2%)
- electrical appliances such as computers/fridges (known as WEEE – waste electrical and electronic equipment – see Figure 5.8) (less than 5%)
- rubble/bricks (less than 1%)
- ash (less than 1%).

The amount will vary from place to place, and over time. The total volume of waste generated can be over 800 kg per person per year.

> **Key word definition**
> **Biodegradable** means capable of being broken down by natural biological processes – for example, through the activities of decomposer organisms.

Figure 5.8 The WEEE man at the Eden Project, Cornwall, England, by sculptor Paul Benomini, standing 7 m tall, weighing 3.3 tonnes
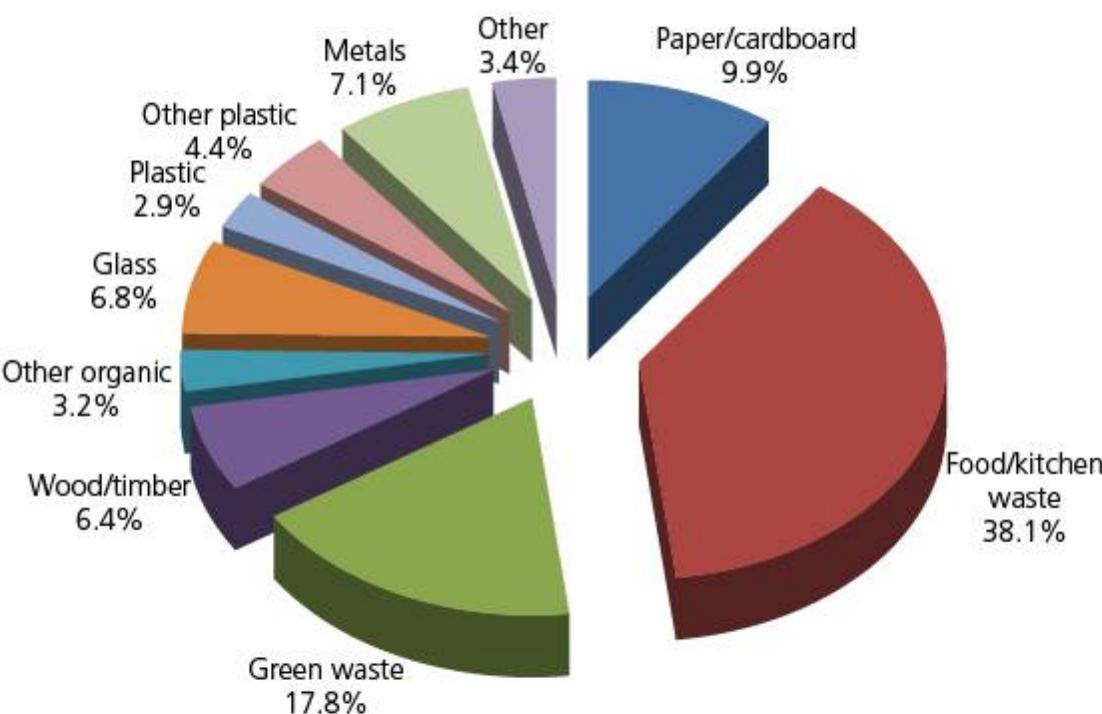
Figure 5.9 Composition of household waste, Victoria, Australia

> **Expert tip**
> You should consider your own and your community's generation of waste. Consider the different types of material – for example, paper, glass, metal, plastics, organic waste (kitchen or garden), packaging – as well as their total volume. Keep a record of your waste for a week.

> **Common mistake**
> Nappies are a form of solid domestic waste, but faeces are not.

■ **QUICK CHECK QUESTIONS**

23 Identify the type of waste that we might expect to increase around Christmas time.
24 Explain how the volume of waste is likely to vary for a household in Tokyo (Japan) and one in Kabul (Afghanistan).

Pollution management strategies for solid domestic (municipal) waste

Recycling

Figure 5.10 Recycling

Table 5.6 Advantages and disadvantages of recycling

Advantages	Disadvantages
■ Reduced amount of energy required to recycle compared with exploiting the resource. ■ It reduces the amount of resources used. ■ It maintains stocks of non-renewable and replenishable resources. ■ It reduces the amount of material in landfill sites. ■ It can be used to make new products. ■ It reduces greenhouse gas emissions. ■ It creates new job opportunities.	■ It involves transport of sometimes heavy, bulky goods, so requires lots of energy. ■ It can produce toxic waste. ■ It can be labour intensive. ■ It can be uneconomic in terms of demand and supply factors.

Reuse

Table 5.7 Advantages and disadvantages of reuse

Advantages	Disadvantages
■ Little energy is used. ■ It provides cheap resources for people of limited means.	■ It can require energy to clean the products being reused (e.g. milk bottles). ■ The products may be heavy to transport (e.g. milk bottles). ■ The products will eventually wear out and must be disposed of.

Composting

Table 5.8 Advantages and disadvantages of composting

Advantages	Disadvantages
■ It produces fertiliser. ■ It reduces the volume of waste. ■ It reduces the use of chemical fertilisers.	■ It produces unpleasant smells. ■ It can attract vermin if not done properly. ■ It requires effort and space. ■ It takes time.

Incineration

Table 5.9 Advantages and disadvantages of incineration

Advantages	Disadvantages
■ It reduces the volume of waste, thereby reducing the need for landfill. ■ The heat produced can be used in place of burning fossil fuels. ■ It kills pathogens. ■ It produces ash for construction. ■ It is a way of producing energy from waste.	■ It releases toxic chemicals. ■ It produces greenhouse gases. ■ Ash still needs disposal. ■ It is expensive. ■ There may be considerable community resistance to the building of new incinerators.

Landfill

Table 5.10 Advantages and disadvantages of landfill

Advantages	Disadvantages
■ It is a cheap and easy way to dispose of waste. ■ It is a way of producing energy (in the form of methane) from waste. ■ Relatively limited amounts of time and labour are required. ■ It can create land (e.g. in Hong Kong).	■ Leachate can pollute watercourses and groundwater. ■ It gives off unpleasant odours. ■ It increases vermin, which can cause disease to spread. ■ It produces methane, which is a greenhouse gas. ■ It takes up land area, and in many places (e.g. New York, USA) there is a limited amount of space available for landfill. ■ There is potential of subsidence and/or contamination of future building land.

Factors affecting the choice of waste disposal

At a national scale there are a number of factors that affect the choice of waste disposal. These include:

- government policy (e.g. strategy to encourage recycling)
- population density and the amount of land available for landfill
- involvement in international agreements to cut greenhouse gases or dumping at sea
- involvement of significant environmental pressure groups (e.g. Greenpeace) in influencing attitudes
- geographic/climate characteristics (e.g. access to coastline)
- economic considerations (e.g. costs of energy and transport).

Expert tip

Many poorer communities are much better at recycling and reusing materials. In Dharavi, Mumbai, for example, recycling and reuse forms the basis of many industries.

Common mistake

Recycling and reuse is not carbon-free. Many greenhouse gases are used in the transport and cleaning of materials.

■ **QUICK CHECK QUESTIONS**

25 State **two** disadvantages of recycling.
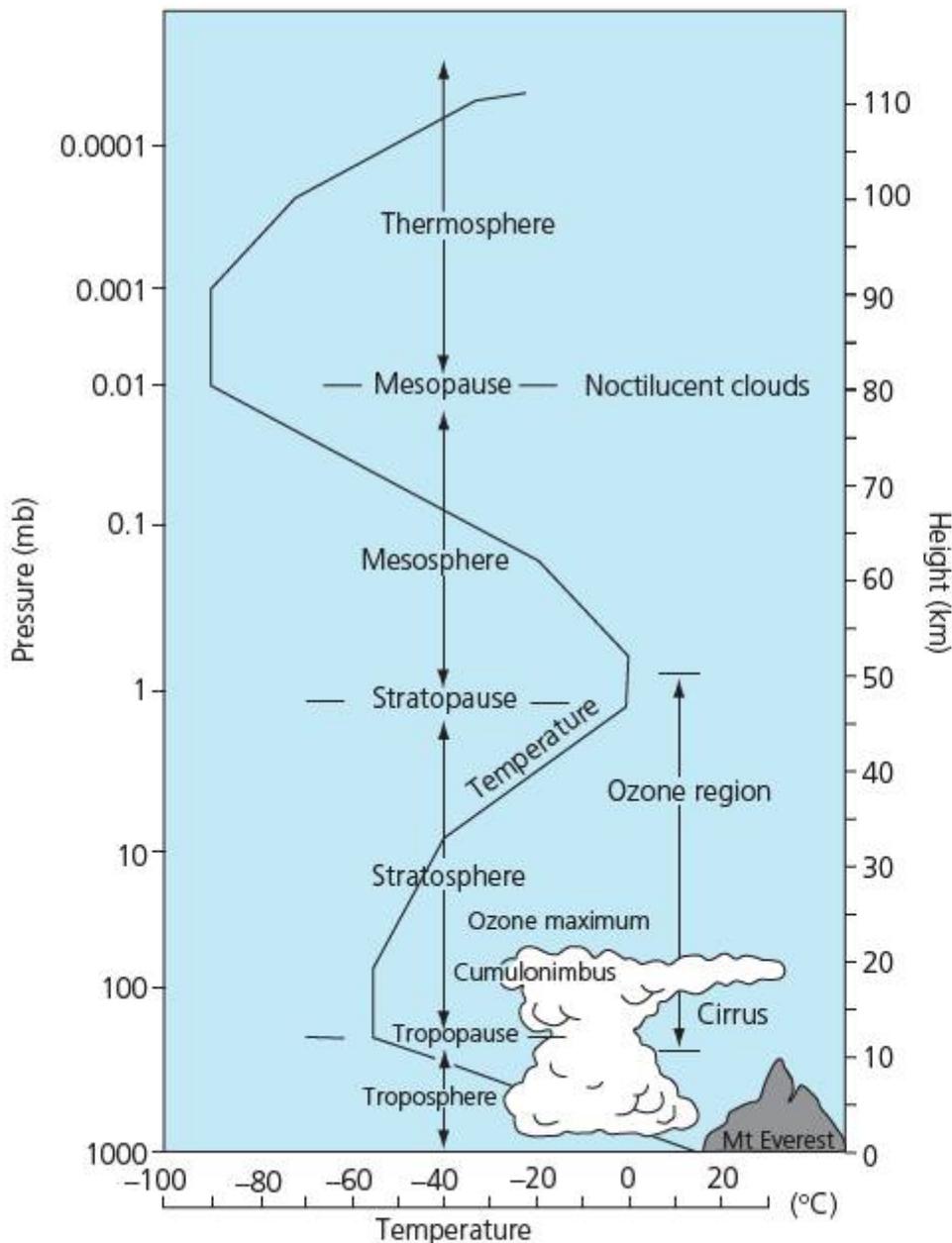26 State **two** advantages of landfill.

EXAM PRACTICE

5   Explain how the use of waste to generate energy can produce greenhouse gases. [4]

Depletion of stratospheric ozone

The structure and composition of the atmosphere

The generalised vertical distribution of temperature and pressure up to about 110 km. Note particularly the tropopause and the zone of maximum ozone concentration with the warm layer above.

Figure 5.11 The structure of the atmosphere

- The atmosphere is the mixture of solids, liquids and gases that are held to the Earth by gravitational force.
- Up to a height of around 80 km the atmosphere is fairly similar, consisting of nitrogen (78%), oxygen (21%), argon (0.9%) and a variety of other trace gases such as carbon dioxide, helium and ozone.
- In addition it contains water vapour and solids (aerosols), such as dust, ash and soot.
- There is no outer limit for the atmosphere, but most 'weather' occurs in the lowest 16–17 km, the troposphere.
- In the troposphere, temperatures fall with height.
- Certain gases are concentrated at certain heights.
- Ozone occurs in the stratosphere (Figure 5.11), mostly at around 25–30 km, and is important for the filtering of harmful ultraviolet radiation.

The role of ozone in the absorption of ultraviolet radiation

Ultraviolet radiation is absorbed during the formation and destruction of ozone from oxygen:

■ Ozone absorbs ultraviolet radiation.
■ It also absorbs some out-going long-wave radiation, so it is a greenhouse gas too.
■ Ozone is created by oxygen rising up from the top of the troposphere and reacting with sunlight.
■ Short-wave (ultraviolet) radiation breaks down oxygen molecules into two separate oxygen atoms.
■ The oxygen atoms (O) combine with oxygen molecules (O_2) to form ozone (O_3).
■ Ozone can be destroyed naturally. In winter, clouds of ice particles form in the upper atmosphere. Chemical reactions take place on the ice involving chlorine. This can destroy ozone. By the summer, the ice clouds have disappeared and the destruction of ozone ceases.
■ Human activities can also destroy ozone.

> **■ QUICK CHECK QUESTIONS**
> 27 In which part of the atmosphere is the ozone that protects against ultraviolet radiation found?
> 28 In which part of the atmosphere is the ozone that is damaging to human health found?

> **Expert tip**
> You are not required to memorise chemical equations.

> **Common mistake**
> There are two types of ozone – stratospheric and tropospheric.
> ■ Stratospheric ozone is the high-level ozone that protects us from ultraviolet radiation.
> ■ Tropospheric ozone or ground-level ozone is the 'bad' ozone that causes poor air quality and respiratory problems.

The interaction between ozone and halogenated organic gases

The chemicals that cause stratospheric ozone depletion include halocarbons, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl bromide, bromine and halons. These are found in refrigerators, air conditioners, aerosols, foamed plastics, pesticides, fire extinguishers and solvents.

Halogenated organic gases are very stable under normal conditions but can liberate halogen atoms when exposed to ultraviolet radiation in the stratosphere. These atoms react with monatomic oxygen and slow the rate of ozone re-formation.

Pollutants enhance the destruction of ozone, thereby disturbing the equilibrium of the ozone production system. These pollutants cause 'holes' in the ozone layer. This in turns lets through ultraviolet radiation, which can be very damaging.

There is a clear seasonal pattern to the concentration of ozone. Each spring time there is a marked reduction in the amount of ozone over Antarctica. As summer develops, the ozone layer recovers. This is because in winter air over Antarctica becomes cut off from the rest of the atmosphere.

The intense cold allows the formation of clouds of ice particles, upon which chemical reactions involving chlorine can take place. In spring the chlorine atoms destroy ozone but by summer the ice clouds have disappeared and there is less destruction of ozone.

> **Key word definition**
> **Halogenated organic gases**, usually known as halocarbons, were first identified as depleting the ozone layer in the stratosphere. They are now known to be potent greenhouse gases. The best-known are chlorofluorocarbons (CFCs).

The effects of ultraviolet radiation on living tissues and biological productivity

The effects of ultraviolet radiation include mutation and subsequent effects on health, as well as damage to photosynthetic organisms, especially phytoplankton, and their consumers such as zooplankton.

- Increased ultraviolet radiation is damaging to ecosystems that contribute significantly to global biodiversity, by damaging plant tissues, and causing the death of primary producers.
- It damages marine phytoplankton, which are some of the major primary producers of the biosphere.
- It causes reduced rates of photosynthesis.
- It is damaging to human populations around the world.
- It contributes to increased health costs.
- There are social and economic impacts of skin cancer and eye damage (cataracts).
- It can cause genetic mutations in DNA.

Expert tip

Although the ozone 'holes' are located over Antarctica and the Arctic, the impacts of ozone depletion are worldwide.

Common mistake

The ozone 'hole' is not actually a hole but is a thinning of the concentration of ozone in the stratosphere.

■ **QUICK CHECK QUESTIONS**

29 State what is meant by the term *ozone hole*.
30 Identify **two** effects of increased ultraviolet radiation.

Methods of reducing the manufacture and release of ozone-depleting substances

Revised

Methods of reducing the manufacture and release of ozone-depleting substances (ODS) include, for example, recycling refrigerants, alternatives to gas-blown plastics, alternative propellants and alternatives to the pesticide methyl bromide (bromomethane).

- Fridges with ODS refrigeration can be replaced with 'green freeze' technology that uses propane and/or butane.
- Pump-action sprays can be used instead of aerosols.
- Alternatives to aerosols can be used – for example, soap rather than shaving foam.
- Organic methods of pest control can be used instead of methyl bromide.
- Old CFC coolants in fridges and air conditioning units can be recycled.
- To protect against excessive ultraviolet radiation people can wear sunglasses, use sun block (sun cream), wear T-shirts and stay inside during the hottest part of the day.

The role of national and international organisations in reducing emissions of ozone-depleting substances

Revised

The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is the most significant and successful international agreement relating to an environmental issue, with many governments signing up and implementing the agreed changes. Subsequent revisions have reduced the phasing-out timescale because of the Protocol's success – phase out in Europe was achieved by 2000, and global phase out is expected by 2030.

The Protocol raised public awareness of the use of CFCs and provided an incentive for countries to find alternatives. Technology has been transferred to LEDCs to allow them to replace ozone-depleting substances, but some of the substances used are still ozone depleting, for example HCFCs. Some HCFCs have been replaced by HFCs (hydrofluorocarbons), but these are powerful greenhouse gases.

In spite of the success, there are issues that are hard to overcome:

- It is harder for LEDCs to implement changes.
- The second-hand appliance market means that old fridges are still in circulation.
- It is a protocol that depends on national governments being willing to comply.
- The longlife of the chemicals in the atmosphere means that damage will continue for some time – until 2100.

Common mistake

Some students confuse global warming and ozone depletion by describing the Kyoto Protocol as relating to ozone depletion – this is incorrect. The Montreal Protocol relates to ODS.

Expert tip

Remember to relate the potential solutions to ODS to the causes, release of pollutants, and impacts, as shown in Figure 5.5.

■ **QUICK CHECK QUESTIONS**

31 Identify ways in which it is possible to reduce the impact of ozone depletion on human health.
32 Identify the ODS management strategies that attempt to deal with the causes of the pollution.

EXAM PRACTICE

6 Compare technocentric and ecocentric approaches to the management of ozone depletion. [6]

Urban air pollution

Sources of tropospheric ozone

- Tropospheric or ground-level ozone is a pollutant.
- It is a secondary pollutant because it is formed by reactions involving oxides of nitrogen (NOx).
- When fossil fuels are burned, two of the pollutants emitted are hydrocarbons (from unburned fuel) and nitrogen monoxide (NO).
- Nitrogen monoxide reacts with oxygen to form nitrogen dioxide (NO_2), a brown gas that contributes to urban haze.
- Nitrogen dioxide can also absorb sunlight and break up to release oxygen atoms that combine with oxygen in the air to form ozone.
- The main source of NOx is road transport.

Effects of tropospheric ozone

- Ozone is a toxic gas and an oxidising agent.
- It damages crops and forests, irritates eyes, can cause breathing difficulties in humans and may increase susceptibility to infection.
- Ground-level ozone reduces plant photosynthesis and can reduce crop yields significantly.
- Ozone pollution has been suggested as a possible cause of the dieback of German forests (previously it was believed these had died as a result of acidification).
- It is highly reactive and can attack fabrics and rubber materials.

The formation of photochemical smog

- Photochemical **smog** is a mixture of about one hundred primary and secondary pollutants formed under the influence of sunlight. Ozone is the main pollutant.
- Fossil fuels are burned and nitrogen oxides are released in vehicle emissions. In the presence of sunlight, these pollutants interact with others (e.g. volatile organic compounds) to produce (tropospheric) ozone.
- Ozone formation can take a number of hours, hence the polluted air may have drifted into suburban and surrounding areas.
- Smog is more likely under high-pressure (calm) conditions. Rain cleans the air and winds disperse the smog – these effects are associated with low-pressure conditions.
- The frequency and severity of photochemical smog in an area depend on local topography, climate, population density and fossil fuel use.

Key word definition
Smog is the term now used for any haziness in the atmosphere caused by air pollutants. Photochemical smog is produced through the effect of ultraviolet light on the products of internal combustion engines. It may contain ozone and is damaging to the human respiratory system and eyes.

- Urban microclimates also affect the production of ground level ozone. Urban areas generally have less vegetation than surrounding rural areas, and the concentration of buildings, industries and offices generate much heat.
- Thermal (temperature) inversions trap the smog in valleys and basins – as in the cases of Los Angeles, Santiago, Mexico City, Rio de Janeiro, São Paulo and Beijing. The air is unable to disperse since cold air from the surrounding mountains and hills prevents the warm air from rising (Figure 5.12). Cold air is denser than warm air and so traps the warm air below.
- Concentrations of air pollutants can build to harmful and even lethal levels, producing toxic and carcinogenic chemicals.

Expert tip

Larger cities with more vehicles will produce more tropospheric ozone than smaller cities.
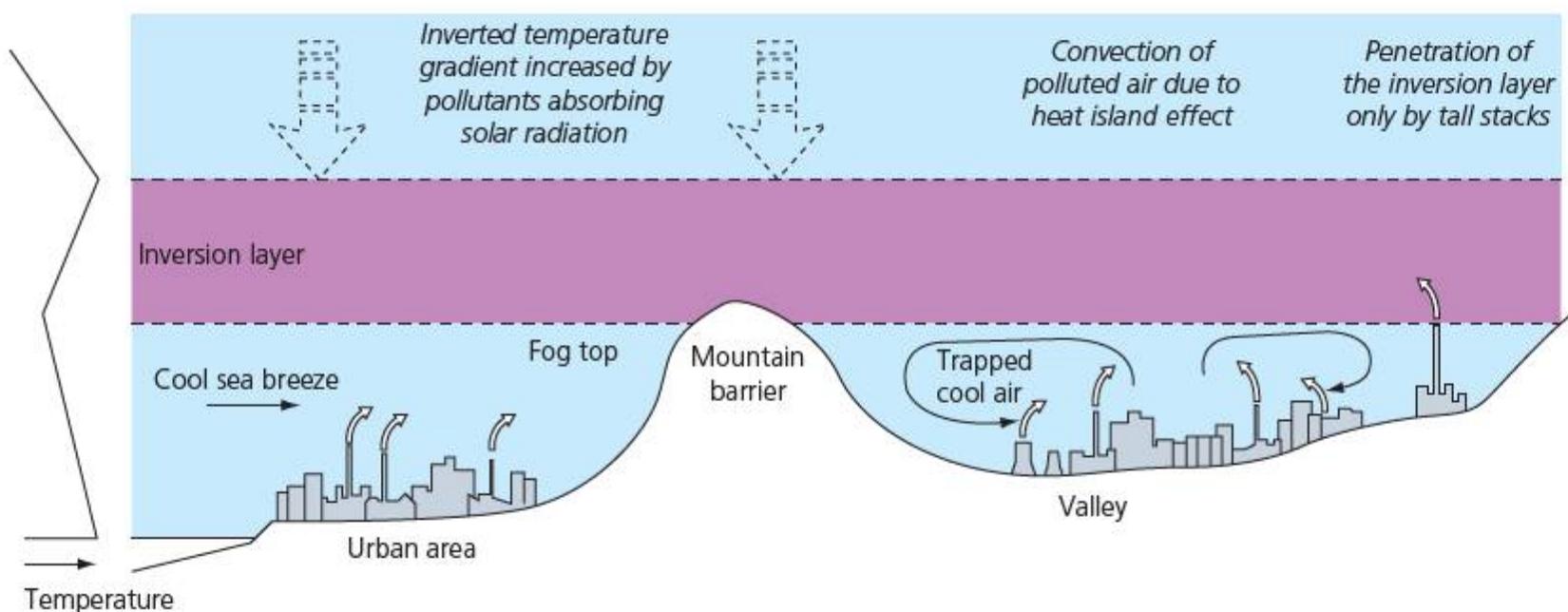
Figure 5.12 Temperature inversion

■ QUICK CHECK QUESTIONS

33 Explain what is meant by the term *temperature inversion*.
34 Why is ozone a problem in areas experiencing atmospheric high pressure?

Common mistake

Areas suffering the worst effects of ozone are not necessarily the areas that produced the pollution – ozone-polluted air can drift into suburban areas as it takes a number of hours to form in sunlight.

Pollution management strategies for urban air pollution

Revised

There are many management strategies for tackling urban air pollution:
- Reducing fossil fuel combustion is an effective way of limiting the release of pollutants.
- Increased use of public transport can reduce total emissions of fossil fuels.
- Promotion of clean technology/hybrid cars.
- Provision of park-and-ride schemes to limit the number of cars entering urban areas.
- Preventing cars from parts of the city i.e. pedestrianising part of the centre (e.g. Curitiba, Brazil).
- Only allowing certain cars into a city – e.g. those with odd-numbered registration plates on certain days, even numbered ones on other days (e.g. Mexico City).
- Fit cars with catalytic convertors to reduce emissions of NOx.
- Reducing fossil fuel combustion by switching to renewable energy methods.
- Reducing fossil fuel combustion through urban design (e.g. south-facing windows, triple-glazed windows, cavity and loft insulation).
- Relocate industries and power stations away from centres of population.
- Ensure industries and power stations have tall chimneys to help disperse pollutants.
- Filter and catch pollutants at the point of emission.
- Design cities so that there are more open spaces and water courses to help reduce the temperature and allow evaporative cooling (e.g. the restoration of the Cheong-Gye-Cheon River in Seoul, South Korea).
- Wear masks to reduce inhalation of pollutants.

However:

- Most urban pollution comes from cars, especially old cars.
- Vehicles using diesel produce emissions of particulate matter.
- Catalytic convertors reduce fuel efficiency and increase CO_2 emissions.
- Public transport can be expensive and may be inconvenient.
- Sustainable urban design is expensive.

■ QUICK CHECK QUESTIONS

35 Suggest how cars can be prevented from entering a city centre.
36 Suggest how urban design can help reduce the incidence of petrochemical smogs.

EXAM PRACTICE

7 Discuss, with reference to examples, the human factors which affect the successful implementation of pollution management strategies.   [6]

Expert tip

You should consider measures to reduce fossil fuel combustion – for example, reducing demand for electricity and private cars and switching to renewable energy. Refer also to clean-up measures such as catalytic converters.

Common mistake

Many students suggest that catalytic convertors are an example of how to tackle emissions of NOx, which is correct, but they fail to mention that they increase CO_2 emissions and reduce fuel efficiency.

Acid deposition

Revised ☐

The formation of acidified precipitation

Revised ☐

Rain is naturally acidic – because of carbon dioxide in the atmosphere – with a pH of about 5.6. Acid rain – or, more precisely, acid deposition – is the increased acidity of rainfall and dry deposition, as a result of human activity. The major causes of acid rain are the sulfur dioxide and nitrogen oxides produced when fossil fuels such as coal, oil and gas are burned. Sulfur dioxide and nitrogen oxides are released into the atmosphere where they can be absorbed by the moisture and become weak sulfuric and nitric acids, sometimes with a pH of around 3.

Dry deposition typically occurs close to the source of emission and causes damage to buildings and structures (Figure 5.13). **Wet deposition**, by contrast, occurs when the acids are dissolved in precipitation, and can fall at great distances from the sources. Wet deposition is an example of a 'trans-frontier' pollution, as it crosses international boundaries.

Expert tip

Knowledge of chemical equations is not required.
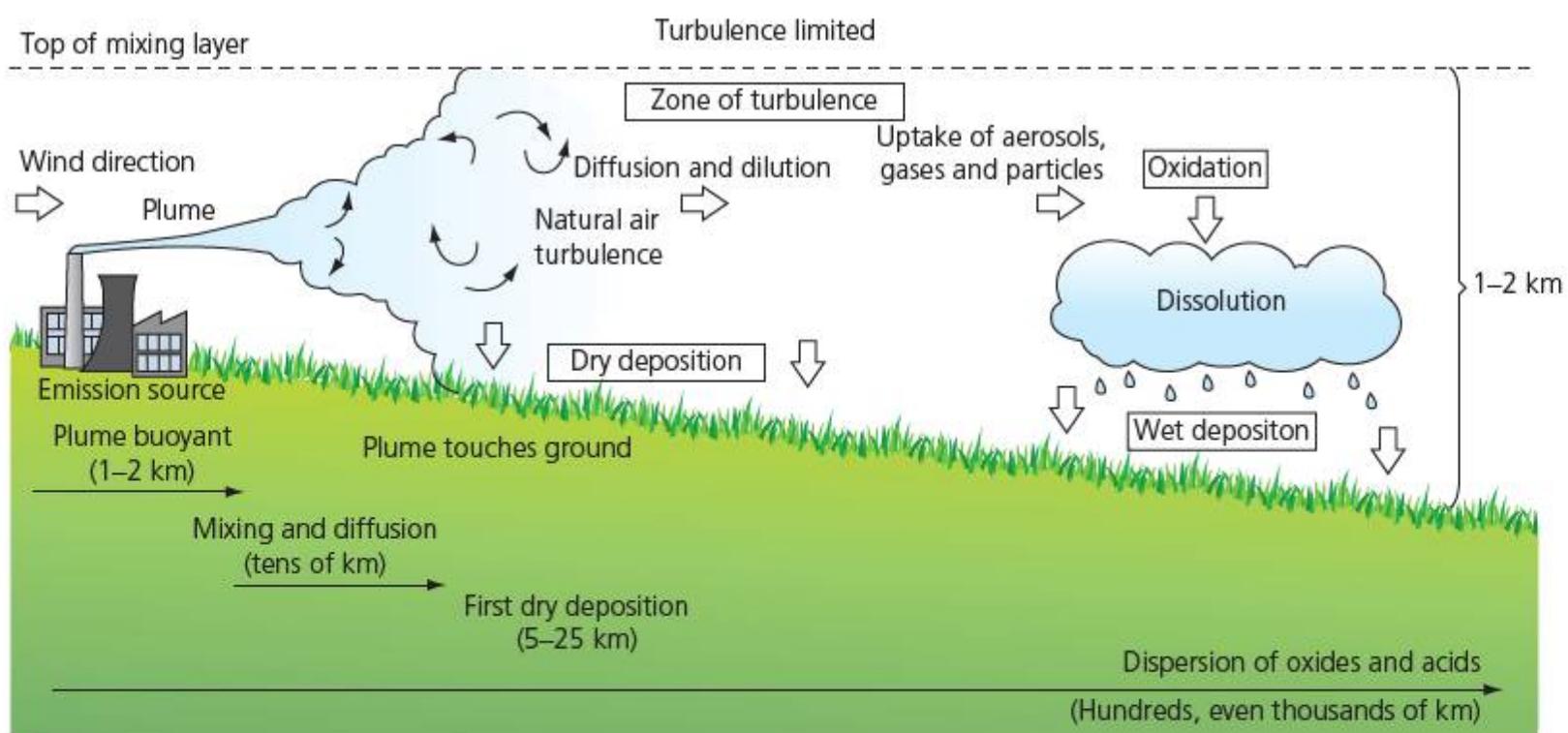
Figure 5.13 Acid deposition

Effects of acid deposition on soil, water and living organisms

Acidic rainfall has a major impact on coniferous trees (Figure 5.14). Coniferous trees are more at risk than deciduous trees because they do not shed their leaves at the end of the year. Trees can also take up toxic aluminium ions from the soil.

In soils, increasing acidity leads to falling numbers of fungi, bacteria and earthworms. Earthworms cannot tolerate soils with a pH of below 4.5.

With increased acidity, more calcium and magnesium can be leached from a soil, while metals, especially iron and aluminium, are mobilised by acidic water and flushed into streams and lakes. Aluminium damages fish gills, causing mucus to build up, thereby making breathing difficult.

Common mistake

Many students forget about dry deposition when referring to acid deposition. Both wet and dry deposition are important – dry deposition tends to be local, whereas wet deposition is more regional in scale.

Acid deposition

Gas, aerosol and particles

Thinning of crown (crown die-back)

Decreased resistance to drought, disease, frost etc.

Shedding of leaves and needles

Direct damage to needles, leaves and bark

Tree weakened by:
• lack of nutrients
• excess of poisons

Loss of nutrients from leaves (leaching) e.g. Ca, Mg

Failure of seedlings

Acidification of top soil

Changes in organic life

Decomposition slowed down

Soil acidification

Damage to fine root hairs

Nutrients washed away (e.g. Mg, Ca)

Poisonous heavy metals mobilised

Reduced intake of water and nutrients

Figure 5.14 The impact of acid rain on coniferous trees

■ QUICK CHECK QUESTIONS

37 Identify the **two** chemicals associated with acid deposition.
38 Describe **one** impact of acidification on coniferous trees and **one** impact on soils, as shown in Figure 5.14.

Regional effects of acidification

Figure 5.13 showed that dry deposition typically occurs close to the source of emission and causes damage to buildings and structures, whereas wet deposition occurs when the acids are dissolved in precipitation, and may fall at great distances from the sources.

The main areas experiencing acid rain are those areas downwind of major industrial regions such as Scandinavia (downwind from Western Europe), northeast USA and eastern Canada (downwind from the US industrial belt). There is less acidification in Scandinavia now compared with the 1980s, as there is less heavy industry in Western Europe. Areas that are increasingly causing acidification include China and India.

Areas experiencing acidification usually have a combination of being downwind from industrial belts and fossil fuel power stations, have high rainfall, contain lots of forests and lakes, and have thin soils.

Some environments are able to neutralise the affects of acid rain. This is referred to as their **buffering capacity**. For example, chalk and limestone areas are very alkaline and can neutralise acids very effectively. The underlying rocks over much of Scandinavia, Scotland and northern Canada are granite. These are naturally acid, and have a very low buffering capacity. It is in these areas that there is the worst damage from acid rain.

Pollution management strategies for acid deposition

Various methods are used to try to reduce the damaging effects of acid deposition. One of these is to add powdered limestone to lakes to increase their pH values. However, the only really effective and practical long-term treatment is to curb the emissions of the offending gases. This can be achieved in a variety of ways:

- by reducing the demand for electricity
- by reducing the amount of fossil fuel combustion
- use of low-sulfur fossil fuels
- use of alternative energy sources that do not produce nitrate or sulfate gases (e.g. hydropower or nuclear power)
- by removing the pollutants before they reach the atmosphere
- use of limestone scrubbers in chimneys of power stations (to neutralise the acid)
- spraying powdered limestone onto acidified soils or waters.

International agreements concerning acidification

- The 1979 Convention on Long-Range Transboundary Air Pollution was important for the clean-up of acid rain in Europe.
- The 1999 Gothenburg Protocol commits countries to reducing emissions of sulfur dioxide, oxides of nitrogen, VOCs and ammonia in an attempt to reduce acidification, eutrophication and ground-level ozone.
- The 1991 Air Quality Agreement between the USA and Canada focused on acid rain and, later, smog.

> **Expert tip**
>
> The case against SO_2 and NO_2 is not clear-cut. While victims and environmentalists stress the risks of acidification, industrialists stress the uncertainties. For example:
>
> - Rainfall is naturally acidic and could cause some of the damage.
> - No single industry/country is the sole emitter of SO_2/NOx – so it is impossible to apportion blame.
> - Car owners with catalytic convertors reduce emissions of NOx.
> - Different types of coal have variable sulfur content – some coal is 'cleaner' than others.

> **Common mistake**
>
> Some students think that acidification is no longer a problem as less SO_2 is being emitted. Although less coal is being burnt in some countries, the increase in the number of cars more than compensates for this.

■ QUICK CHECK QUESTIONS

39 Identify the rocks that offer the best buffering against acidification.
40 Explain how adding powdered lime can combat acidification.

EXAM PRACTICE

8 Evaluate the role of reducing, reusing and recycling strategies in the management of atmospheric pollutants. [9]

Topic 6 The issue of global warming

The greenhouse effect

The role of greenhouse gases in maintaining mean global temperature

The greenhouse effect is a normal and necessary condition for life on Earth. **Greenhouse gases** allow incoming short-wave radiation to pass through the atmosphere and heat up the Earth's surface. They trap a proportion of the out-going long-wave radiation from the Earth – hence the atmosphere is heated from below rather than from above (Figure 6.1). In this way greenhouse gases raise the Earth's temperature by about 33°C and make life on Earth possible.

> **Key word definition**
> **Greenhouse gases** are those atmospheric gases that absorb infrared radiation, causing world temperatures to be warmer than they would otherwise be. This process is sometimes known as 'radiation trapping'. The natural greenhouse effect is caused mainly by water and carbon dioxide. Human activities have led to an increase in the levels of carbon dioxide, methane and nitrous oxide (dinitrogen oxide, N_2O) in the atmosphere, and there are fears that this may lead to **global warming**.

2. As this short-wave energy passes through the atmosphere it might hit dust particles or water droplets and be scattered or reflected.

6. Some long-wave energy escapes into space.

5. Long-wave energy is quite easily absorbed by naturally occurring greenhouse gases in the atmosphere. Of these, carbon dioxide is by far the most abundant.

1. Solar energy enters the atmosphere.

3. Only a little short-wave radiation is absorbed in the atmosphere.

4. Solar energy heats the Earth's surface, which then radiates long-wave (heat) energy into the atmosphere.

Key
→ Short-wave energy
→ Long-wave energy

Figure 6.1 The greenhouse effect

Carbon dioxide (CO_2) levels in geological times

—— Temperature variation —— CO_2 concentration
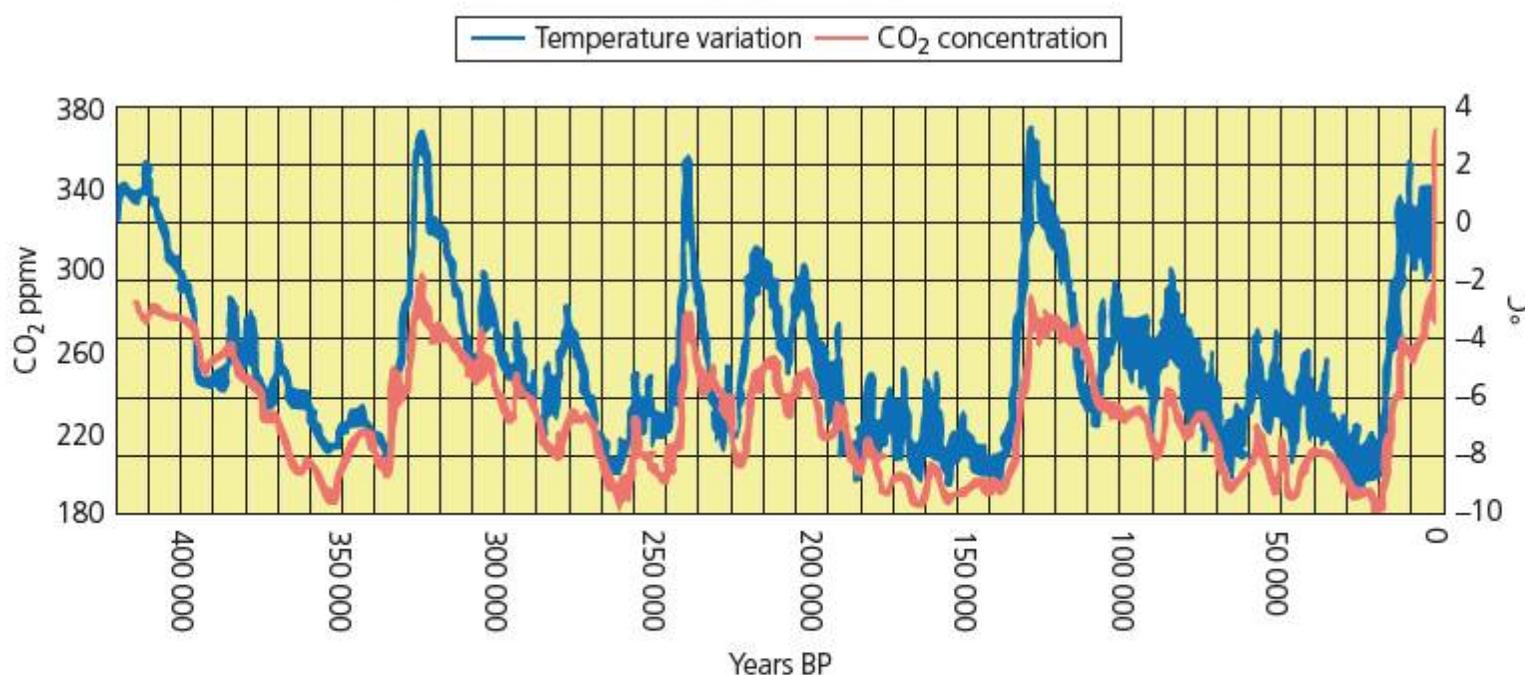
Figure 6.2 Carbon dioxide levels in geological time

There have been considerable changes in the levels of carbon dioxide in the geological past (Figure 6.2). Generally, higher levels of carbon dioxide correlate with higher temperatures, and lower levels of carbon dioxide correlate with lower temperatures.

■ **QUICK CHECK QUESTIONS**
1   Briefly describe the greenhouse effect.
2   Describe the relationship between carbon dioxide and temperature as shown on Figure 6.2.

Human activities and greenhouse gases

The main greenhouse gases include water vapour, carbon dioxide, methane, CFCs, ozone and oxides of nitrogen. Human activities are increasing levels of carbon dioxide, methane and CFCs in the atmosphere, which may lead to **global warming**.

Key word definition
Global warming is an increase in average temperature of the Earth's atmosphere.

Legend:
- Carbon dioxide
- CFCs, HFCs
- Methane
- Oxides of nitrogen
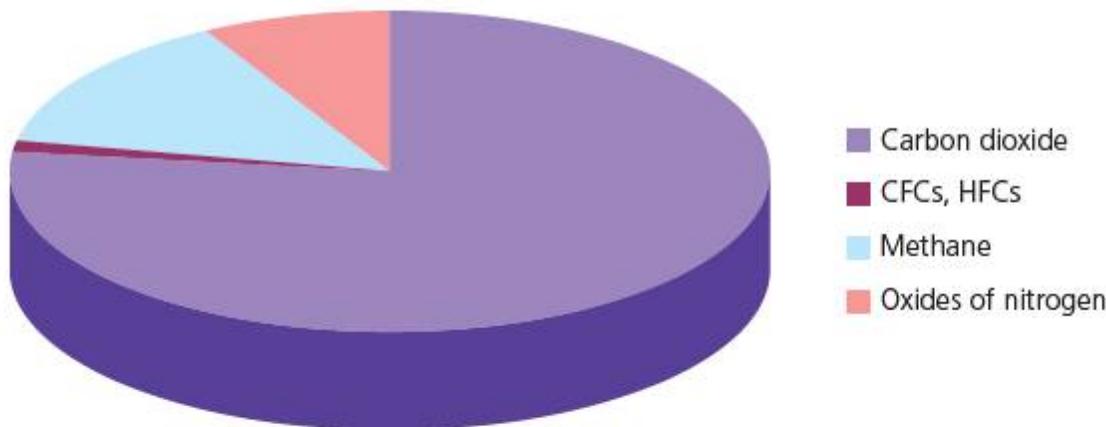
Figure 6.3 The main greenhouse gas emissions related to human activity

■ Sources of carbon dioxide include respiration by living organisms, breakdown of organic material, volcanic vents, burning of fossil fuels and organic materials, and forest fires.
■ There are many different sources of methane including wetlands, bogs, stagnant water bodies, rice paddies, tundra soils, the breakdown of organic material, volcanic vents, livestock, landfill sites, melting of permafrost, and manure or sewage.
■ Sources of CFCs include refrigeration and air conditioning systems, plastic foams, aerosol cans and solvents used in the electronics industry.

Common mistake

Many people forget that water vapour is a greenhouse gas, although it is not considered to be a human-related greenhouse gas. Its exact role is unclear.

Expert tip

Although there are some sources of carbon dioxide and methane that are the same, such as volcanic vents and the breakdown of organic matter, you need to give different sources rather than the same one for carbon dioxide and methane.

Legend:
- Energy
- Industrial processes
- Land use changes
- Agriculture
- Waste
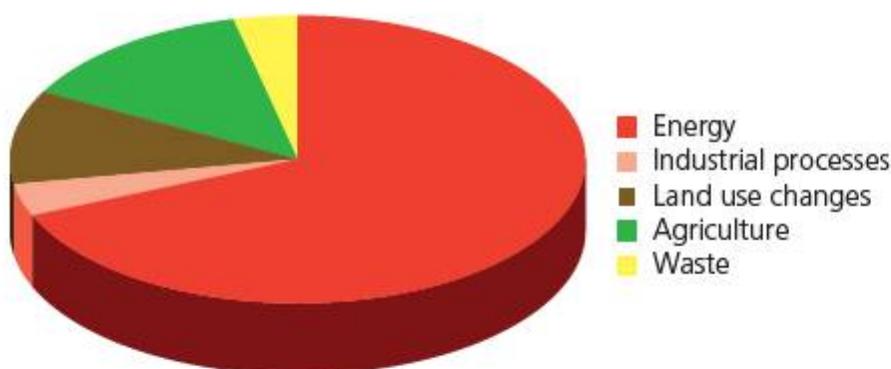
Figure 6.4 Sources of human-related greenhouse gases

■ **QUICK CHECK QUESTIONS**
3   Identify the main source of human-related (anthropogenic) emissions of greenhouse gases.
4   List the anthropogenic greenhouse gases in descending order of emissions.

The potential effects of increased mean global temperature

The potential effects on the distribution of biomes, global agriculture and human societies might be adverse or beneficial, for example:
- biomes shifting
- change in location of crop-growing areas
- changed weather patterns
- coastal inundation (due to thermal expansion of the oceans and melting of the polar ice caps)
- human health (spread of tropical diseases).

Changes in biotic components of ecosystems

Table 6.1 Changes in biotic components of ecosystems and their impact

Changes	Impacts/significance for humans
■ Biomes shift to higher latitudes/altitudes as climate changes ■ Expansion of areas inhabited by tropical disease vectors such as mosquitoes ■ Loss of species diversity as species are unable to adapt or have limited scope for shifting, and become extinct ■ Animals can migrate but plants shift their range more slowly ■ Increased rates of primary productivity	■ Shifting biomes mean crop-growing areas will shift ■ Some areas will change in terms of productivity ■ A shortage of resources could lead to increased conflict, for example over water or food ■ Impact on human health as more areas become affected by tropical diseases ■ Loss of economic, aesthetic and/or medical benefits of species diversity

Coastal inundation

Coastal inundation (flooding) will occur as global warming will lead to thermal expansion of water and melting of (land-based) glaciers and ice caps, leading to a sea-level rise. This could have many impacts:
- increased coastal erosion
- intrusion of salty water
- reduction of mangrove forests
- coral reefs unable to obtain sufficient light
- wading birds struggling to obtain food
- contamination of soils and a decline in agricultural production.

Impact on human health

Global warming could have a varied impact on human health:
- an increase in stagnant water, meaning more mosquitoes that carry diseases
- people forced to leave their homes and becoming more susceptible to diseases, especially children and the elderly
- changes in distributions of organisms, bringing new diseases to areas
- saltwater intrusion onto coastal agricultural land, meaning a reduction in food production, and leading to more widespread hunger and malnutrition, increasing the impact of diseases.

Changes in weather patterns

Researchers suggest that a doubling of CO_2 from the base line value of 270 ppm (parts per million) to 540 ppm would lead to:
- an increase in temperatures of around 2°C, although increased warming is likely to be greater at the poles rather than at the Equator
- changes in prevailing winds
- changes in precipitation
- continental areas becoming drier.

CASE STUDY

THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE UK

Positive impacts might include:

- an increase in timber yields (up to 25% by the 2050s), especially the north of the UK (with perhaps some decrease in the south)
- a northward shift of farming zones by about 200–300 km per degree centigrade of warming, or 50–80 km per decade, would improve some forms of agriculture, especially pastoral farming in the northwest
- enhanced potential for tourism and recreation as a result of increased temperatures and reduced precipitation in the summer, especially in the south.

Negative impacts might include:

- an increase in droughts, soil erosion and the shrinkage of clay soils

- an increase in invasive animal – especially insect – species as a result of northward migration from the continent, and a small decrease in the number of plant species due to the loss of northern and montane (mountain) species
- a decrease in crop yields in the southeast
- an increase in river flow in the winter and a decrease in the summer, especially in the south
- an increase in public and agricultural demand for water
- damage from increased storminess, flooding and erosion to natural and human resources and other assets in coastal areas
- increased incidents of certain infectious diseases in humans and of the health effects of episodes of extreme temperature.

Figure 6.5 One potential impact of global warming on the UK – drier soils

Table 6.2 What would be a significant climate change for the UK?

IF THERE IS AN INCREASE OF TEMPERATURE OF 0.5°C…	IF THERE IS AN INCREASE OF TEMPERATURE OF 1°C…	IF THERE IS AN INCREASE OF TEMPERATURE OF 1.5°C…
Summer and winter precipitation increases in the northwest by 2–3%	Summer and winter precipitation increases in the northwest by 4%; some precipitation decreases in the southeast by 5%	Summer and winter precipitation increases in the northwest by about 7%; summer precipitation decreases in the southeast by 7–8%
Annual runoff in the southern UK decreases by 5%	Annual runoff in the southern UK decreases by 10%	Annual runoff in the southern UK decreases by 15%
The frequency of the 1995 type summer (drought) increases from 1:90 to 1:25	Frequency of 1995 type summer increases from 1:90 to 1:10	Frequency of 1995 type summer increases from 1:90 to 1:3
Disappearance from the British Isles of a few niche species, e.g. alpine wood fern and oak fern	Disappearance from the British Isles of certain species, e.g. ptarmigan, mountain hare	Further disappearance from the British Isles of several species
In-migration of some continental species and expansion of some native species, e.g. red admiral and painted lady butterflies, Dartford warbler	Expansion of range of most butterflies, moths and birds, such as goldeneye and redwing	In-migration of several species
Increase in overall UK timber productivity by 3%	Increase in overall UK timber productivity by 7%	Increase in overall UK timber productivity by 15%
Increase in demand for irrigation water by 21% over the increase without climate change, and in domestic demand by an additional 2%	Increase in demand for irrigation water by 42% over the increase without climate change, and in domestic demand by an additional 5%	Increase in demand for irrigation water by 63% over the increase without climate change, and in domestic demand by an additional 7%
Decrease in heating demand by 6%	Decrease in heating demand by 11%	Decrease in heating demand by 16%

■ **QUICK CHECK QUESTIONS**

5   State **one** advantage of rising temperatures for the UK, as shown in Table 6.2.
6   Explain **two** reasons why global warming could lead to an increase in the number of cases of malaria.

Feedback mechanisms associated with an increase in mean global temperature

Revised ☐

There are many examples of feedback in the process of global warming (Figures 6.6 and 6.7). Positive feedback mechanisms occur involving increasing temperatures, melting permafrost and releasing methane. As methane is a greenhouse gas, it has the potential to increase temperatures, thereby reinforcing the rise in temperature.

In contrast, higher temperatures in tropical areas may lead to increased precipitation in many parts of the world. Increased precipitation in polar areas leads to increased snow cover. The surface of snow and ice is very reflective, and so the albedo is increased. Increased reflectivity reduces the amount of solar radiation received and so lowers temperatures.
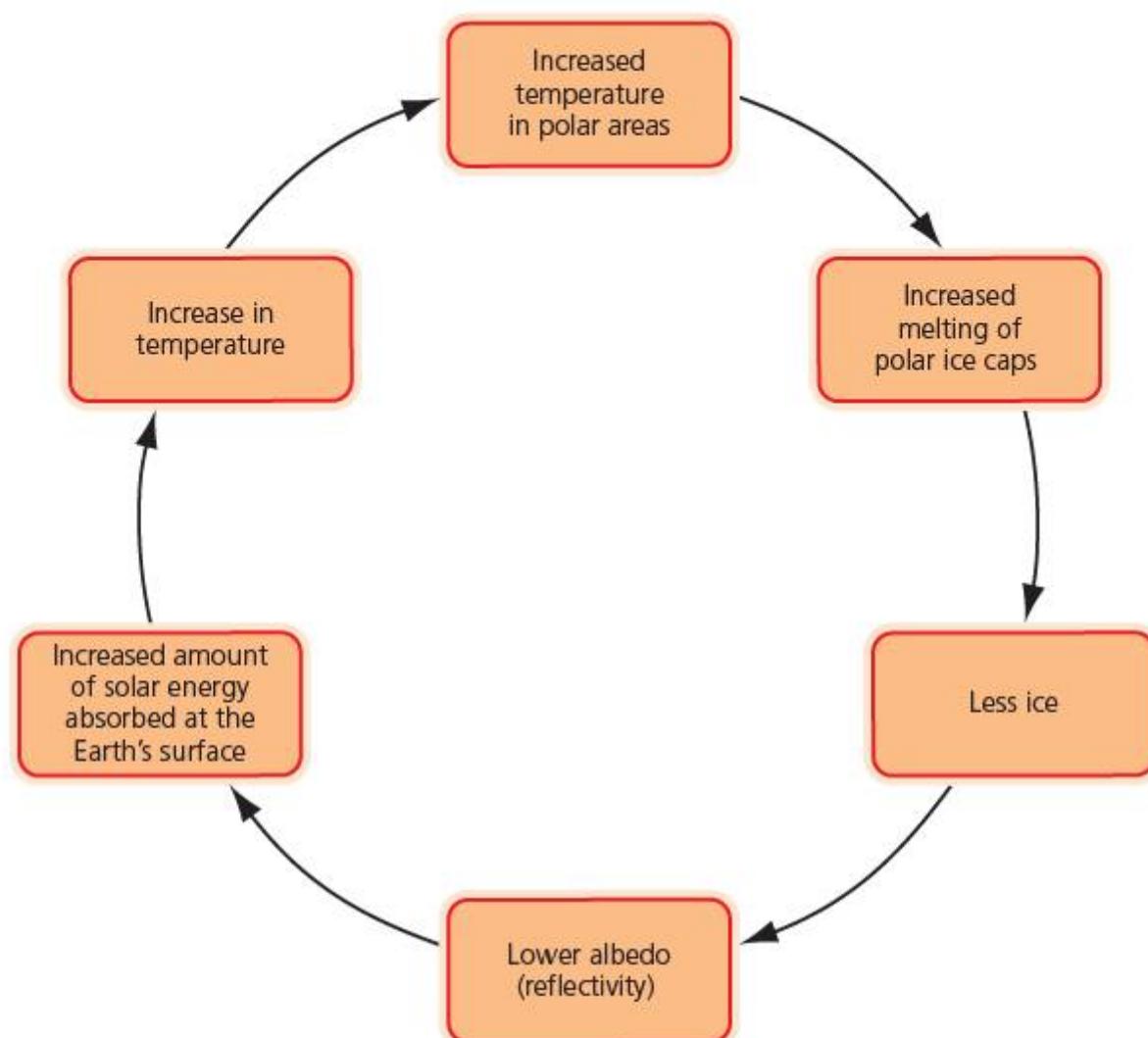
Figure 6.6 Positive feedback in global warming
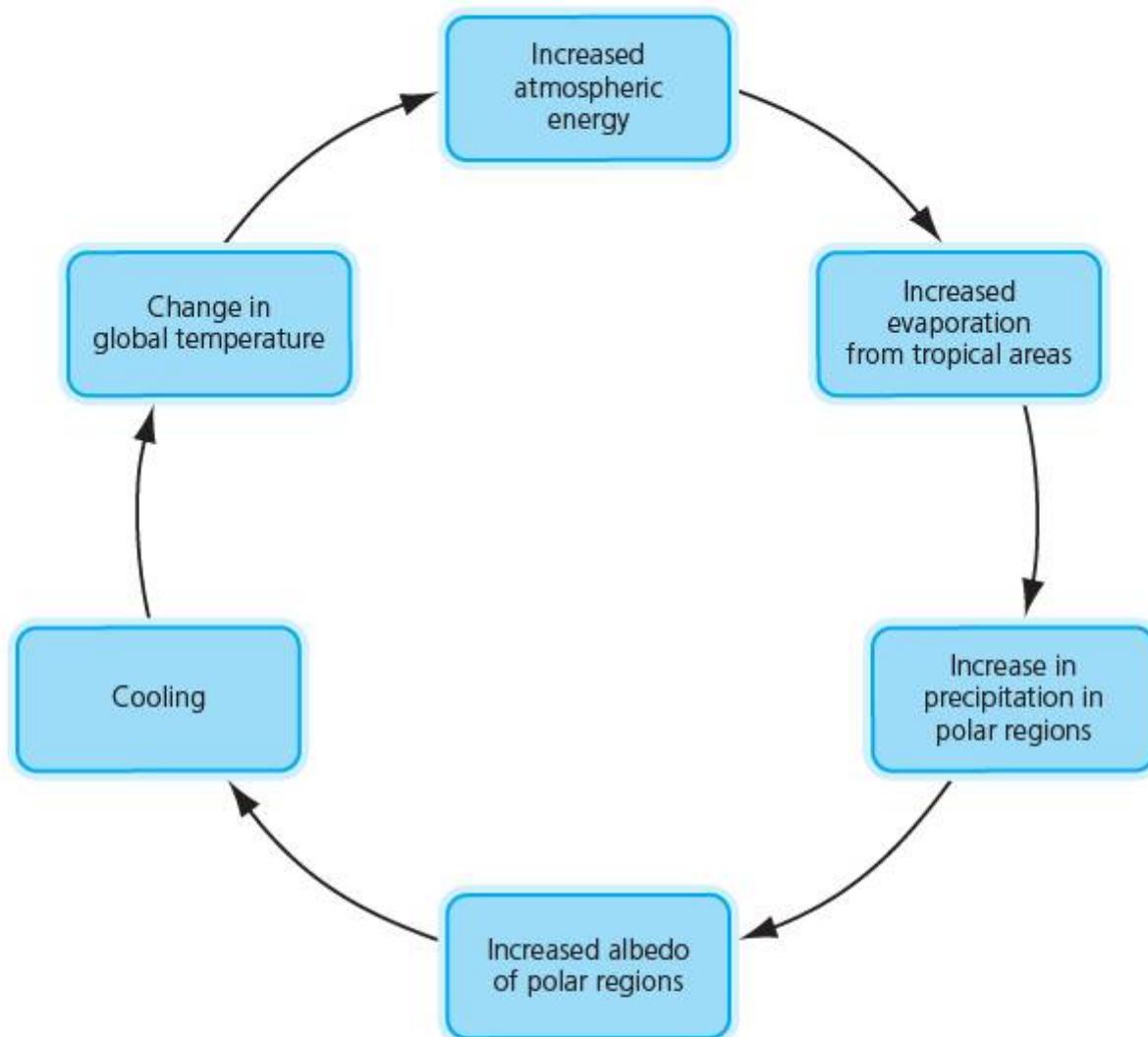
Figure 6.7 Negative feedback in global warming

Expert tip

Be prepared to draw a diagram of positive and/or negative change in relation to global warming.

■ **QUICK CHECK QUESTIONS**

7   Identify the type of feedback that is self-regulating.
8   Identify the type of feedback that leads to instability and change.

Pollution management strategies to address the issue of global warming

Revised ☐

The Kyoto Protocol

The **Kyoto Protocol** (1997) gave all MEDCs legally binding targets for cuts in emissions from the 1990 level by 2008–12. The EU agreed to cut emissions by 8%, Japan by 7% and the USA by 6%. Some countries found it easier to make cuts than others.

Since 1992, when negotiations for the Kyoto Protocol first began, greenhouse gas emissions have risen by 50%. In 2010, despite a global recession, they rose by 5%.

There are three main ways for countries to keep to the Kyoto target without cutting domestic emissions:

■ Install clean technology in other countries and claim carbon credits for themselves.
■ Buy carbon credits from countries such as Russia where traditional heavy industries have declined and the national carbon limits are underused.
■ Plant forests to absorb carbon or change agricultural practices (e.g. keep fewer cattle).

Even if greenhouse gas production is cut by between 60% and 80% there is still enough greenhouse gas in the atmosphere to raise temperatures by 5°C.

The Kyoto Protocol deadline was the end of 2012 (Figure 6.8). However, it was only meant to be the beginning of a long-term process, not the end of one.

At the 2011 Durban (South Africa) conference the debate about a legally binding global agreement was reopened. Countries now have until 2015 to decide how far and how fast they can cut their carbon emissions. Before the

Expert tip

You should consider the following pollution management strategies when answering exam questions:

■ global – intergovernmental and international agreements (for example, the Kyoto Agreement and subsequent updates), carbon tax and carbon trading, alternative energy sources
■ local – explore your lifestyle with respect to greenhouse gas emissions.

Consider both preventive and reactive strategies.

Durban conference, most countries were going to follow national targets for carbon emissions after 2012, which would be voluntary and not legally binding.

The Durban Agreement differs from the Kyoto Protocol in that it includes LEDCs as well as MEDCs. It differs from other summits in that it is working towards a legally binding treaty.

Just one day after committing to the new road map, Canada pulled out of the Kyoto Protocol altogether because it was unable to fulfil its obligations. It was due to reduce its greenhouse emissions by 6% in 2012, but its emissions have risen by 30%. Canada would have to pay some $14 billion to buy carbon credits from other countries.
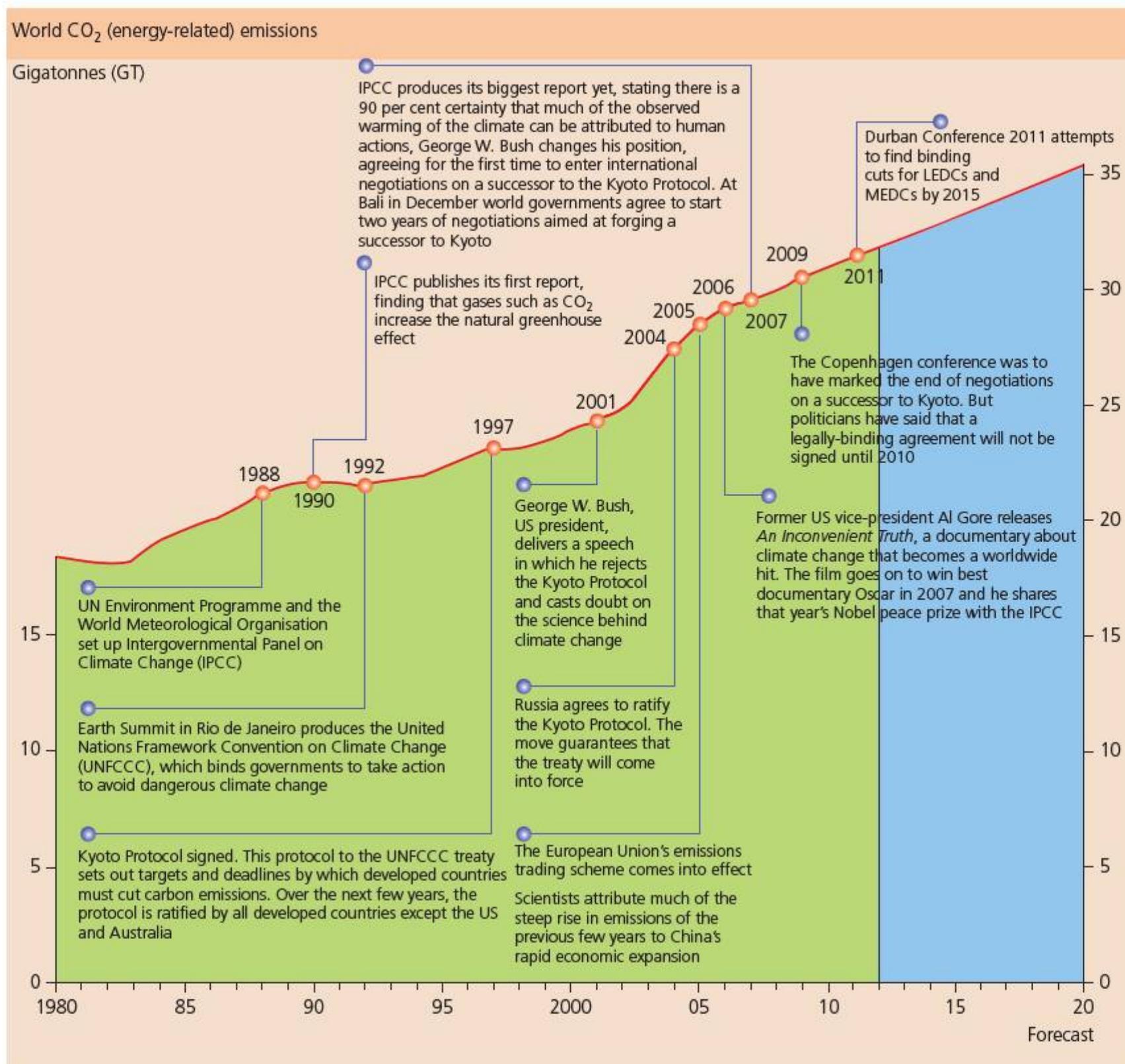
Figure 6.8 The chronology of attempts to tackle global warming

Individuals' reductions in greenhouse gases

There are many ways in which individuals can reduce their own emissions of greenhouse gases:

- Use public transport.
- Walk or ride a bike for local trips.
- Turn off lights when leaving a room.
- Reduce the use of heating and air conditioning.
- Eat locally produced food.

■ **QUICK CHECK QUESTIONS**
9 In what year did the Kyoto Protocol 'run out'?
10 Identify the Conference that is attempting to find legally binding cuts in CO_2 by 2015.

Common mistake

Some students consider preventive and reactive strategies to be the same – this is not the case.

■ Preventive strategies prevent global warming from taking place. Any strategy that prevents fossil fuels from being burnt is a preventive strategy.

■ Reactive strategies try to treat the symptoms of global warming – attempts to reduce carbon emissions are a reaction to the build-up of greenhouse gases.

Expert tip

You should evaluate these strategies with regard to their effectiveness and the implications for MEDCs and LEDCs of reducing CO_2 emissions in terms of economic growth and national development.

The arguments surrounding global warming

Revised ▢

Theories regarding global warming

Some critics state that even if humans are causing climate change, the Earth will correct itself – this relates in part to the **Gaia hypothesis**, i.e. that the Earth is a self-regulating entity.

Those who believe that human-induced global warming is real

Some claim that the scientific data prove that the climate is warming. Data from a variety of sources show that carbon dioxide levels and greenhouse gas levels are increasing, and in some cases that temperatures are rising.

They claim that human activities and/or fossil fuel combustion are known to increase carbon dioxide/greenhouse gas levels, and insist that carbon dioxide and other greenhouse gases are known to affect global temperatures. Therefore it is likely that human activities are resulting in global climate change. Moreover, the rapid rate of increase in carbon dioxide levels implies a human link.

Those who dismiss global warming

Some people claim that natural fluctuations occur, so changes in climate could still be a short-term trend. They argue that the only technologically verifiable data have been collected from a short period of time.

They also state that other aspects of climate change are not all fully understood and that climate has changed in the past. This is in part due to natural fluctuations such as Milankovitch cycles (variations in the Earth's orbit around the Sun, in the length of seasons and in the orientation of the poles towards or away from the Sun).

Moreover, current carbon dioxide levels and global temperature fluctuations are moderate compared with geologic history (see Figure 6.1). Therefore it is not conclusive that humans are causing global climate change.

Global dimming

Global dimming refers to a reduction in global temperatures as a result of pollution.

In the 3 days after the 9/11 attacks on the World Trade Center, daily temperatures increased by an average of 1.1°C. The cause of this increase was the grounding of airlines in the interests of national security. The absence of vapour trails left behind by high-flying aircraft (Figure 6.9), and the absence of small droplets (aerosols) they form, caused this effect.

Figure 6.9 Contrails, the vapour trails that form behind aircraft

Aerosols are highly reflective and reflect solar energy, thereby blocking it from entering the lower atmosphere, which has a cooling effect. Air pollution has a similar impact. Scientists who discovered the phenomenon called it 'global dimming'.

It is possible that global dimming has slowed down global warming. Ironically, therefore, by cleaning up air pollution, climate change may be accelerated.

Scientists showed that from the 1950s to the early 1990s, the level of solar energy reaching the Earth's surface dropped 9% in Antarctica, 10% in the USA, and almost 30% in Russia due to high levels of pollution at that time.

Natural particles in clean air provide points of attachment for water. Polluted air contains far more particles than clean air (e.g. ash, soot, sulfur dioxide etc.) and therefore provides many sites for water to bind to. These tend to be smaller than natural droplets. The many small water droplets reflect more sunlight than a few larger ones, so polluted clouds reflect far more light back into space, preventing the Sun's heat from getting through.

The mechanism of global dimming works because not only are the particles over polluted areas themselves reflecting more sunlight, but also the water droplets formed around these particles reflect more light.

Common mistake

There are natural causes of climate change as well as human-induced causes. Just because the natural ones exist this does not mean that there is no human impact on climate change.

Expert tip

You should appreciate the variety of conflicting arguments surrounding this issue. You should also note the complexity of the problem and the uncertainty of global climate models.

You should be aware of the concept of global dimming due to increased levels of atmospheric pollution.

■ **QUICK CHECK QUESTIONS**

11 Explain the term *global dimming*.
12 Identify **one** natural cause of climate change.

Contrasting human perceptions of the issue of global warming

Revised ☐

There are many different viewpoints about global warming and these can change over time:

■ 350.org is an organisation building a global movement to solve the climate crisis.
■ Al Gore's book and film *An Inconvenient Truth* managed to get the message about global warming to many of the US public. However, some critics argue that it was only the effects of Hurricane Katrina (and later Hurricane Sandy) that awoke many Americans to the idea that global warming was having an impact on the USA.
■ In a similar way, some climate experts believe that the 2013 Australian heatwave will prove a turning point in how Australians respond to warnings

about human-induced climate change. In a country that relies on fossil fuels for much of its wealth (coal is its second largest export and produces about 80% of its electricity), climate-change sceptics have often swayed political action.

- In *The Skeptical Environmentalist*, Bjorn Lomborg argues that there are too many uncertainties regarding global warming, although he accepts that human activity is adding to it.
- In *The Great Global Warming Swindle*, Martin Durkin argues that global warming is more likely to be caused by natural variations such as Sunspot activity.

EXAM PRACTICE

1   Describe ecocentric and technocentric responses to global warming and justify which may be more effective in reducing the impacts of global warming. [8]

Topic 7 Environmental value systems

Environmental value systems and philosophies

Social systems

Environmental value systems, like all systems, have inputs and outputs:

- Outputs of an environmental system are determined by processing the inputs.
- Outputs can be modified by personal characteristics (e.g. age, gender, strong-willed vs compliant, optimistic vs pessimistic) and emotions.

Environmental value systems work within **social systems**. Both social systems and ecosystems exist at different scales, and have common features such as feedback and equilibrium.

> **Key word definition**
> **Environmental value system** refers to a particular worldview that shapes the way an individual or group of people perceives and evaluates environmental issues.
>
> A **society** is an arbitrary group of individuals who share some common characteristic such as geographical location, cultural background, historical timeframe, religious perspective, value system and so on.

Figure 7.1 Environmental value systems: inputs and outputs

> **Expert tip**
> Make sure you know the definition for environmental value system. Although not one of the glossary definitions, you need to understand this concept. It will be influenced by cultural (including religious), economic and socio-political context.

Table 7.1 Comparing social systems and ecosystems

	Social system	Ecosystem
Flows	Information, ideas and people	Energy and matter
Storage	Ideas and beliefs	Biomass; the atmosphere; soils; lakes, rivers, sea
Levels	Social levels (i.e. hierarchy)	Trophic levels
Producers	People responsible for new input (e.g. ideas, books, films)	Plants, algae and some bacteria
Consumers	Absorb and process new input (e.g. ideas, food, material possessions)	Consume other organisms

Range of environmental philosophies

Environmental value systems can be applied to a range of **environmental philosophies**. An environmental philosophy determines the global perspective of an individual or group of individuals, the decisions they make, and the course of action they take regarding environmental issues.

Ecocentrism is a nature-centred environmental philosophy. An ecocentrist worldview sees nature as having an inherent value:

- Involving minimum disturbance of natural processes.
- Combining spiritual, social and environmental aspects.
- Aiming for sustainability for the whole Earth.
- Involving self-imposed restraint of natural resource use.

Anthropocentrism is a people-centred environmental philosophy. It believes that it is important for everyone in society to participate in environmental decision making:

- People act as the managers of sustainable global systems.
- Management requires strong regulation by independent authorities.
- Participation has an important role to help educate people about environmental issues.
- Participation means that people who might be causing the problems are less likely to do so if they are involved in decisions about their own environment.
- Sometimes less powerful groups in society have the best knowledge about what is right for an environment, e.g. indigenous groups.
- People who believe in democracy argue that everyone has a right to have a say in how communal natural resources are managed.
- Ecosystems need to be managed holistically so people from all walks of life should be able to contribute.
- It includes **self-reliant soft ecologists** who: are more conservative about environmental problem solving than deep ecologists; emphasise smallness of scale and therefore community identity in work and leisure; lack faith in modern, large-scale technology; believe that materialism for its own sake is wrong; believe that economic growth can be geared to even the poorest people.
- It includes **environmental managers** who: believe that economic growth and resource exploitation can continue if carefully managed; believe that laws and regulation can manage natural resources; appreciate that preserving biodiversity can have economic and ecological advantages; believe in compensation for those who experience adverse environmental or social effects.

Technocentrism is a technology-centred environmental philosophy. A technocentrist worldview sees technology as providing solutions to environmental problems even when human effects are pushing natural systems beyond their normal boundaries:

- Technology can keep pace with, and provide solutions to, environmental problems.
- Resource replacement can reduce resource depletion.
- There is a need to understand natural processes in order to control them.
- Emphasis should be on scientific research and prediction before policymaking.
- Emphasis should be on sustained market and economic growth.

Specific groups representing different environmental philosophies lie on the spectrum from ecocentrism through to technocentrism, with **deep ecologists** and **cornucopians** at opposite ends of the environmental values system continuum (Table 7.2).

> **Expert tip**
>
> You may be asked to comment on how people's different philosophies (e.g. deep ecologists vs cornucopians) influence how they respond to environmental issues covered in the course (e.g. energy supply, water shortage, farming methods), and how this affects decision-making processes.

> **Common mistake**
>
> Take care not to oversimplify the views of ecocentrism and technocentrism by making claims such as 'ecocentrics don't believe in technology' and 'technocentrics don't care about the environment'. You need to use the level of detail shown in Tables 7.2 and 7.3.

Table 7.2 Comparing the environmental value systems of deep ecologists and cornucopians

	Deep ecologist	Cornucopian
Role of nature	■ See humans as subject to nature, not in control of it ■ It is of intrinsic importance for the existence of humanity	■ Nature is there to be made use of by humanity ■ Humans can control their environment
Role of humanity	■ More value placed on nature than on humanity ■ Ecological laws dictate human morality	■ Humans have the ability to improve the conditions of the Earth's peoples and they have the ingenuity to overcome any difficulties
Biodiversity	■ Believe in the inherent right to life and intrinsic value of species ■ Place most value on bio-rights, i.e. favour the rights of species to remain free from harm over the rights of humans who wish to exploit resources for economic gain	■ See biodiversity as a resource to be exploited for economic gain ■ Less concern for intrinsic or ethical rights of biodiversity

Table 7.2 *(Continued)*

	Deep ecologist	Cornucopian
Consumption	■ Nature is more important than material gain for its own sake	■ Resources are there to be exploited and to generate income
Modern, large-scale technology	■ Distrust and lack faith in it	■ See it as providing the solutions to humanity's environmental issues
Economic growth	■ Should not occur at the expense of natural resources and the environment ■ Should be geared to providing the needs of the poorest people	■ Forms the basis of all projects and policies
Environmental problems	■ Need to be tackled at source and ideally prevented in the first place	■ People can always find solutions to political, scientific or technological difficulties

Decision making on environmental issues

Revised

Table 7.3 Comparing the advantages and disadvantages of ecocentric and technocentric responses to environmental issues

	Advantages	Disadvantages
Ecocentrism	■ Approaches are more sustainable ■ Responses aim to minimise impact on the environment by encouraging restraint ■ Promotes methods more in harmony with natural systems ■ Does not have to wait for technological developments to occur ■ Raises general environmental awareness in communities	■ Conservation can be costly, with little economic return ■ May be unpopular with countries seeking economic development ■ May hinder economic growth and development ■ Requires individual change, which can be difficult to encourage
Technocentrism	■ Provides alternatives that don't inconvenience people ■ Substitutes materials and so avoids costly industrial change ■ Allows economic, social and technological development to continue	■ Technological solutions may give rise to further environmental problems ■ Substituting does not solve the problem of consumerism ■ Allows for greater resource consumption ■ High costs

Common mistake

A question may ask you to discuss two contrasting environmental problems. The contrast can be one of cause or scale. If you do not pick two very different environmental issues you will lose marks. Appropriate contrasting issues would be, for example, climate change and biodiversity loss.

Expert tip

If asked to evaluate a response to an environmental problem, an appropriate answer might be: technology is a tool that cannot on its own solve any problem, there has to be political will (anthropocentric involvement and commitment from people) to make changes and then technology can help to provide solutions; people are reluctant to adapt lifestyles or accept lowered standard of living, so ecocentric approaches can be hard to enforce.

<table>
<tr><td>Worked example</td></tr>
</table>

Describe and evaluate ecocentric and technocentric responses to eutrophication.

Ecocentric:

■ Encourage methods that are in balance with natural systems – for example, use animal dung on agricultural fields or crop rotation, so that less or no fertiliser is needed.

■ Encourage people to use less detergent through educational campaigns to promote more environmentally friendly detergent (i.e. zero or low phosphate).

■ Plant a buffer zone between fields and water courses to absorb any runoff from fields treated with fertiliser.

Technocentric:

■ Promote the use of alternative materials such as alternatives to phosphates in detergents.

■ Apply fertilisers more carefully so there is reduced runoff.

■ Use technology to screen water and to remove pollutants – for example, phosphate stripping.

■ Pump air through lakes to avoid the low-oxygen conditions.

■ Remove nutrient-enriched sediments from water courses – for example through mud pumping.

Evaluation:

■ Ecocentric approaches are difficult to enforce as people are reluctant to change their lifestyles.

■ Alternative approaches such as organic fertilisers may not work effectively and can still result in eutrophication.

■ Technocentric solutions might increase costs – for example, research to develop new detergents requires financial commitments.

■ They do not get to the main cause of the problem.

■ Technocentric solutions provide a short-term solution but are unsustainable in the long term.

■ They may not be an option in LEDCs.

■ Technology can help to provide solutions only if there is a political will and commitment from people to make changes.

■ **QUICK CHECK QUESTIONS**

1 Define the term *environmental value system*.
2 Compare and contrast social systems and ecosystems.
3 Outline the range of environmental philosophies.
4 Describe the views of an environmental manager.
5 Compare and contrast the environmental views of a deep ecologist and a cornucopian.

Development of the modern environmental movement

Revised

Key historical events have influenced the development of the modern environmental movement. Major landmarks include:

■ Minamata:
  □ In 1956 a chemical company released toxic methyl mercury into waste water in Minamata, Japan.
  □ Shellfish and fish were contaminated.
  □ Local people developed illnesses caused by mercury poisoning.
  □ This raised awareness of threats posed by industrialisation.

■ Rachel Carson's *Silent Spring* (1962) raised awareness of the threat of the pesticide DDT to organisms higher up food chains.

■ The Save the Whale campaign (1970s) was coordinated by Greenpeace, which organised direct action to prevent whaling.

■ Bhopal:
  □ In 1984 an explosion at a Union Carbide plant in Bhopal, India, released 42 tonnes of toxic methyl isocyanate gas.
  □ Between 8000 and 10 000 people died within the first 72 hours.
  □ Highlighted to the world how dangerous factories can be.

- The Chernobyl nuclear meltdown in 1986 reinforced negative perceptions of nuclear power in society.
- The UN **Rio Earth Summit** (see also pages 49 and 93):
  - The first UN conference to focus on sustainable development.
  - Attended by 172 nations, so its impact was likely to be felt globally.
  - The summit's message was radical, i.e. that nothing less than a transformation of our attitudes and behaviour would bring about the necessary changes.
  - Led to the adoption of **Agenda 21**, a blueprint for action to achieve sustainable development worldwide.
- *An Inconvenient Truth*:
  - Extensive publicity following release of the film in 2006 meant that many people heard about global warming.
  - A mainstream political figure championed environmental issues for the first time.
  - The film made the arguments about global warming accessible to a wider audience.
  - The film changed people's attitudes and raised awareness about climate change.

Each of these:
- resulted in the creation of environmental pressure groups, both local and global
- promoted the concept of stewardship
- increased media coverage, which raised public awareness.

Attitudes towards the environment change over time:
- When a new resource or product is first developed, people are more likely to see benefits than potential problems, which emerge later (e.g. the car).
- Key events prompt change (see above).
- Environmental pressure groups help to raise awareness by distributing leaflets and staging events (e.g. Greenpeace).
- Environmental attitudes can become politically mainstream when economic consequences of pollution are seen (e.g. the Stern report on global warming).
- School curricula can reflect and promote changing attitudes.
- Changing technologies can help to spread new attitudes (e.g. the internet).
- International organisations (e.g. the United Nations Environment Programme – UNEP) can raise the profile of environmental issues through conferences. These can set targets that take effect through national government strategies (e.g. Agenda 21 – pages 49 and 93).

> **Expert tip**
>
> You do not need to remember all of the historical events that have shaped the environmental movement: questions usually ask you to discuss two or three different events. You will need to explain in detail why each one is important.

> **Common mistake**
>
> There is a tendency in exams to write over-long answers. If you are asked, for example, to describe the role of historical influences in the environmental movement, make sure you give a detailed account appropriate to the number of marks awarded. If two marks are awarded then two different points, no more, are needed.

■ QUICK CHECK QUESTIONS

6   Describe the role of any **four** named historical influences in the environmental movement.
7   Outline how major landmarks have influenced public perception of environmental issues.
8   Describe how attitudes towards the environment can change over time.

Environmental value systems of different societies

Revised ☐

When comparing environmental value systems, suitable contrasting societies would be, for example, Native Americans and European pioneers operating frontier economics, which involved exploitation of seemingly unlimited resources; Buddhist and Judaeo-Christian societies; communist and capitalist societies; shifting cultivators and urban societies.

> **Expert tip**
>
> You need to be able to compare and contrast the environmental value systems of two named societies. The societies chosen should demonstrate significant differences.

Worked example

Compare the attitudes of **two named** contrasting societies towards the natural environment, and discuss the consequences of these attitudes to the way in which natural resources are used.

Example used: indigenous farmers using shifting cultivation in the Amazonian rainforest in Brazil, and city-dwellers in Brasilia.

Indigenous farmers:
- Natural resources are used in a way that minimises impact on the environment.
- Attitudes can broadly be termed 'ecocentric' (give details from Table 7.3).
- Lifestyles and practices are compatible with the forest in which they live – using forest materials to make their homes, canoes, and for medicines.
- Use farming methods that mimic forest structure, for example by maintaining the layered structure of rainforest to protect ground crops from the Sun and heavy downpours.
- Only return to farmed sites after around 50 years to allow soil fertility to be restored.
- They are animists and recognise the spiritual role of the forest, which leads to respect for trees and other species.
- Overall they are less destructive and have a closer connection between social systems and ecological systems.

City-dwellers from Brasilia:
- They see rainforest as a resource to be exploited for economic gain, and underestimate the true value of pristine rainforest.
- Attitudes can broadly be termed 'technocentric' (give details from Table 7.3).
- They have a lack of understanding about how natural systems work, which means they may support decisions that lead to damaging actions (e.g. construction of dams, which then become silted up).
- They may migrate to make use of deforested land, but are unsuccessful as the soil lacks fertility.

Personal viewpoints on environmental issues

Revised ☐
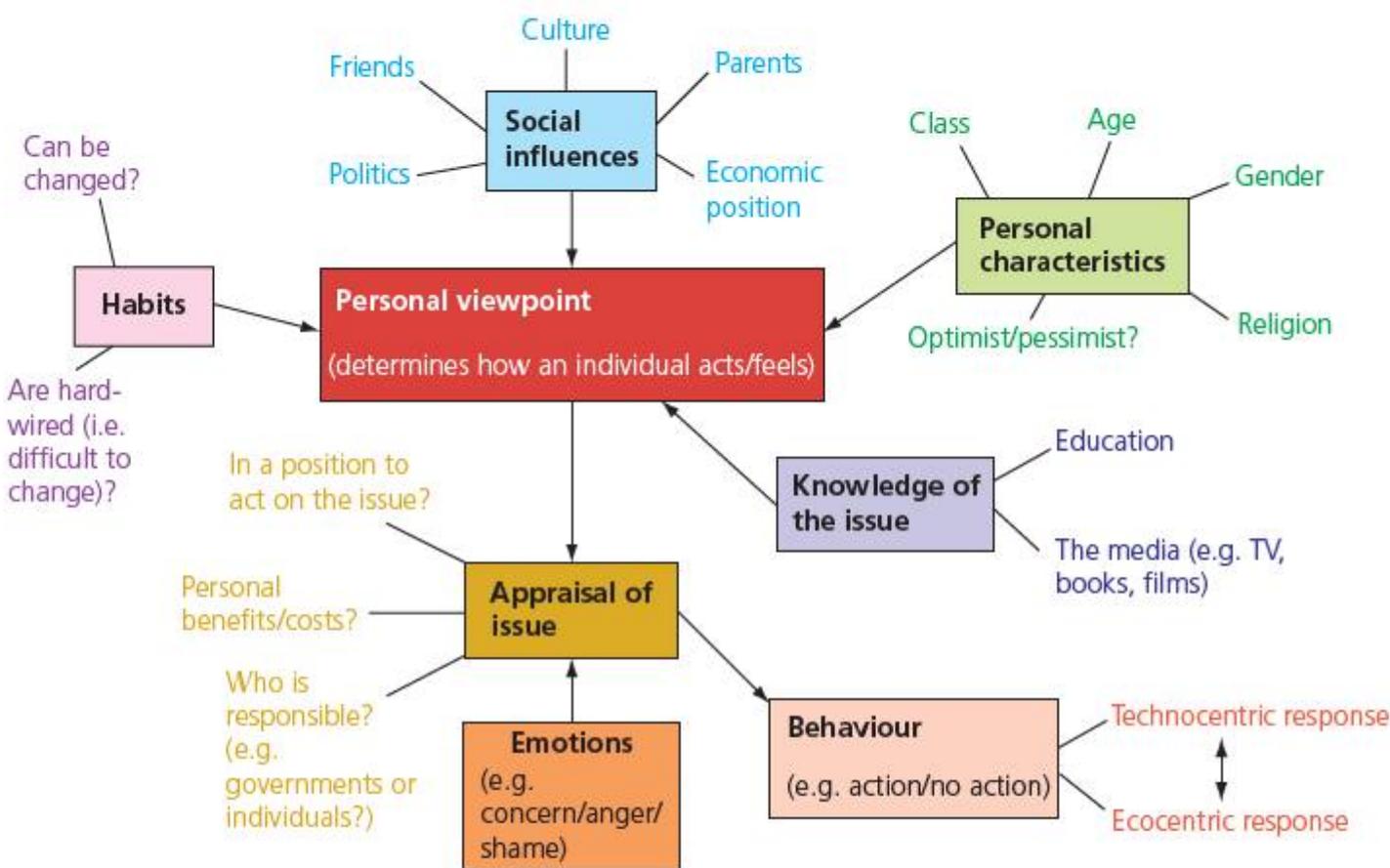
Figure 7.2 Factors that determine personal environmental value systems. These principles can be applied to any of the environmental issues covered by the course. The environmental philosophy of an individual will be shaped by the cultural, economic and socio-political context

■ QUICK CHECK QUESTIONS
9 Compare and contrast the environmental philosophies of **two** contrasting societies.
10 What factors can determine your personal viewpoint on environmental issues?

Expert tip

The course requires you to reflect on where you stand on the spectrum of environmental philosophies. You need to consider your viewpoint on all the environmental issues that you have studied throughout the course, such as population control, resource exploitation, sustainable development and climate change.

EXAM PRACTICE

1 Compare the characteristics of ecosystems and social systems. [5]

2 Compare the likely views of a deep ecologist and a cornucopian on the exploitation of coal reserves in an undisturbed ecosystem. [5]

3 Discuss whether a technocentric or ecocentric approach may be more effective in solving the problem of stratospheric ozone depletion. [6]

4 Outline the arguments that might be given for preserving biodiversity by a deep ecologist and an environmental manager. [4]

5 Identify **three** landmarks in the development of the modern environmental movement, and justify why each one was significant. [9]

6 Justify your personal viewpoint of the environmental issue shown in the following photograph, which shows deforestation in a tropical rainforest. [6]

Are you ready?

Use this checklist to record progress as you revise. Tick each box when you have:
- revised and understood a topic
- tested yourself using the **Quick check questions**
- used the **Exam practice** questions and gone online to check your answers.

Topic 1 Systems and models	Revised	Tested	Exam ready
Systems	☐	☐	☐
Concept and characteristics of systems	☐	☐	☐
Transfer and transformation processes	☐	☐	☐
The systems concept on a range of scales	☐	☐	☐
Open systems, closed systems and isolated systems	☐	☐	☐
The first and second laws of thermodynamics and their relevance to environmental systems	☐	☐	☐
The nature of equilibria			
Positive feedback and negative feedback	☐	☐	☐
Models	☐	☐	☐
Topic 2 The ecosystem			
Structure	☐	☐	☐
Biotic and abiotic components	☐	☐	☐
Food chains and food webs	☐	☐	☐
Pyramids of numbers, biomass and productivity	☐	☐	☐
Pyramid structure and ecosystem functioning	☐	☐	☐
Species, populations, habitats and niches	☐	☐	☐
Population interactions	☐	☐	☐

	Revised	Tested	Exam ready
Measuring abiotic components of the system	☐	☐	☐
Measuring biotic components of the system	☐	☐	☐
Dichotomous keys	☐	☐	☐
Methods for estimating the abundance of organisms	☐	☐	☐
Method for estimating the biomass of trophic levels	☐	☐	☐
Diversity and the Simpson's diversity index	☐	☐	☐
Biomes	☐	☐	☐
Function	☐	☐	☐
The role of producers, consumers and decomposers	☐	☐	☐
Photosynthesis and respiration	☐	☐	☐
Transfer and transformation of energy	☐	☐	☐
Transfer and transformation of materials within an ecosystem	☐	☐	☐
Gross productivity, net productivity, primary productivity and secondary productivity	☐	☐	☐
Gross primary productivity and net primary productivity	☐	☐	☐
Gross secondary productivity and net secondary productivity	☐	☐	☐
Changes	☐	☐	☐
Limiting factors and carrying capacity	☐	☐	☐
S- and J-population curves	☐	☐	☐
Density-dependent and density-independent factors	☐	☐	☐
Survivorship curves	☐	☐	☐
Succession and zonation	☐	☐	☐
Changes through a succession	☐	☐	☐
Climax communities	☐	☐	☐

	Revised	Tested	Exam ready
Measuring changes in the system	☐	☐	☐
Measuring changes along an environmental gradient	☐	☐	☐
Measuring changes due to a specific human activity	☐	☐	☐
Environmental impact assessments	☐	☐	☐
Topic 3 Human population, carrying capacity and resource use			
Population dynamics	☐	☐	☐
The nature and implications of exponential growth in human populations	☐	☐	☐
Birth rate, crude death rate, fertility, doubling time and natural increase rate	☐	☐	☐
Age-sex (population) pyramids	☐	☐	☐
The demographic transition model	☐	☐	☐
The use of models in predicting the growth of human populations	☐	☐	☐
Resources: natural capital	☐	☐	☐
Resources and natural income	☐	☐	☐
Renewable, replenishable and non-renewable natural capital	☐	☐	☐
The dynamic nature of the concept of a resource	☐	☐	☐
The intrinsic value of the environment	☐	☐	☐
Sustainability, natural capital and natural income	☐	☐	☐
Sustainable development	☐	☐	☐
Sustainable yield	☐	☐	☐
Energy resources	☐	☐	☐
The range of energy resources available to society	☐	☐	☐
The advantages and disadvantages of contrasting energy sources	☐	☐	☐

	Revised	Tested	Exam ready
The soil system	☐	☐	☐
Soil characteristics	☐	☐	☐
Soil degradation	☐	☐	☐
Soil conservation measures	☐	☐	☐
Food resources	☐	☐	☐
Issues involved in the imbalance in global food supply	☐	☐	☐
The efficiency of terrestrial and aquatic food production systems	☐	☐	☐
Contrasting food production systems	☐	☐	☐
Links between social systems and food production	☐	☐	☐
Water resources	☐	☐	☐
The Earth's water budget	☐	☐	☐
The sustainability of freshwater resource usage	☐	☐	☐
Limits to growth	☐	☐	☐
Carrying capacity and local human populations	☐	☐	☐
Carrying capacity and recycling, reuse and reduction	☐	☐	☐
Environmental demands of human populations	☐	☐	☐
Ecological footprints	☐	☐	☐
Calculating ecological footprints	☐	☐	☐
Ecological footprints in LEDCs and MEDCs	☐	☐	☐
National and development policies and cultural influences on human population dynamics and growth	☐	☐	☐
The role of technology	☐	☐	☐

Topic 4 Conservation and biodiversity

	Revised	Tested	Exam ready
Biodiversity in ecosystems	☐	☐	☐
Species, habitat and genetic diversity	☐	☐	☐

	Revised	Tested	Exam ready
Natural selection	☐	☐	☐
The role of isolation in forming new species	☐	☐	☐
Plate activity	☐	☐	☐
Ecosystem stability and succession	☐	☐	☐
Evaluating biodiversity and vulnerability	☐	☐	☐
Factors that lead to loss of diversity	☐	☐	☐
Vulnerability of tropical rainforests	☐	☐	☐
Past and present rates of species extinction	☐	☐	☐
Factors that make species prone to extinction	☐	☐	☐
Determining a species' Red List conservation status	☐	☐	☐
Extinct, critically endangered and back from the brink	☐	☐	☐
Natural area of biological significance under threat	☐	☐	☐
Conservation of biodiversity	☐	☐	☐
Arguments for preserving species and habitats	☐	☐	☐
The role of intergovernmental and non-governmental organisations	☐	☐	☐
Designing a protected area	☐	☐	☐
Evaluating the success of a protected area	☐	☐	☐
Strengths and weaknesses of the species-based approach to conservation	☐	☐	☐

Topic 5 Pollution management

	Revised	Tested	Exam ready
Nature of pollution	☐	☐	☐
Pollution	☐	☐	☐
Point-source pollution and non-point-source pollution	☐	☐	☐
The major sources of pollutants	☐	☐	☐

	Revised	Tested	Exam ready
Detection and monitoring of pollution	☐	☐	☐
Direct methods of monitoring pollution	☐	☐	☐
Biochemical oxygen demand (BOD)	☐	☐	☐
Biotic indices	☐	☐	☐
Approaches to pollution management	☐	☐	☐
Pollution management: the process of pollution and strategies for reducing impacts	☐	☐	☐
Human factors that affect the approaches to pollution management	☐	☐	☐
The costs and benefits to society of the WHO's ban on the use of DDT	☐	☐	☐
Eutrophication	☐	☐	☐
The process of eutrophication	☐	☐	☐
The impacts of eutrophication	☐	☐	☐
Pollution management strategies	☐	☐	☐
Solid domestic waste	☐	☐	☐
Types of solid domestic waste	☐	☐	☐
Pollution management strategies for solid domestic (municipal) waste	☐	☐	☐
Depletion of stratospheric ozone	☐	☐	☐
The structure and composition of the atmosphere	☐	☐	☐
The role of ozone in the absorption of ultraviolet radiation	☐	☐	☐
The interaction between ozone and halogenated organic gases	☐	☐	☐
The effects of ultraviolet radiation on living tissues and biological productivity	☐	☐	☐
Methods of reducing the manufacture and release of ozone-depleting substances	☐	☐	☐

	Revised	Tested	Exam ready
The role of national and international organisations in reducing emissions of ozone-depleting substances	☐	☐	☐
Urban air pollution	☐	☐	☐
Sources of tropospheric ozone	☐	☐	☐
Effects of tropospheric ozone	☐	☐	☐
The formation of photochemical smog	☐	☐	☐
Pollution management strategies for urban air pollution	☐	☐	☐
Acid deposition	☐	☐	☐
The formation of acidified precipitation	☐	☐	☐
Effects of acid deposition on soil, water and living organisms	☐	☐	☐
Regional effects of acidification	☐	☐	☐
Pollution management strategies for acid deposition	☐	☐	☐

Topic 6 The issue of global warming

	Revised	Tested	Exam ready
The greenhouse effect	☐	☐	☐
The role of greenhouse gases in maintaining mean global temperature	☐	☐	☐
Human activities and greenhouse gases	☐	☐	☐
The potential effects of increased mean global temperature	☐	☐	☐
Feedback mechanisms associated with an increase in mean global temperature	☐	☐	☐
Pollution management strategies to address the issue of global warming	☐	☐	☐
The arguments surrounding global warming	☐	☐	☐
Contrasting human perceptions of the issue of global warming	☐	☐	☐

Topic 7 Environmental value systems

	Revised	Tested	Exam ready
Environmental value systems and philosophies	☐	☐	☐
Social systems	☐	☐	☐
Range of environmental philosophies	☐	☐	☐
Decision making on environmental issues	☐	☐	☐
Development of the modern environmental movement	☐	☐	☐
Environmental value systems of different societies	☐	☐	☐
Personal viewpoints on environmental issues	☐	☐	☐
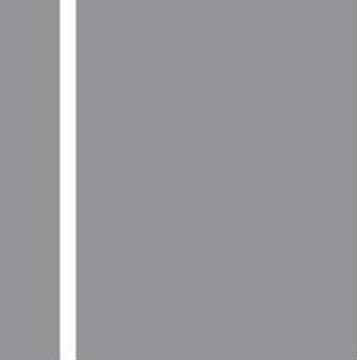
My revision notes

Glossary

Abiotic The non-living part of an ecosystem – for example, air, wind, temperature, water, soil, minerals, landscape, climate.

Adaptive radiation Where an ancestral species evolves to fill different ecological niches, leading to new species.

Agenda 21 An outcome of the Rio Earth Summit. A blueprint for action to achieve sustainable development worldwide; to be implemented at the local level.

Agro-industrialisation The large-scale, intensive, high-input, high-output, commercial nature of much of modern farming.

Anthropocentrism A people-centred environmental philosophy.

Anti-natalist population policy A policy that is trying to reduce the birth rate and thereby population size.

Aquifer Water-bearing rock.

Asthenosphere The part of the upper layer of the mantle just below the lithosphere, which is involved in plate tectonic movement.

Background extinction Extinction at a local level caused by, for example, droughts, floods, habitat loss, disease, the evolution of a superior competitor.

Bacteria Very small, single-celled organisms that do not have a true nucleus.

Baseline study A survey used to measure environmental conditions before development begins, and to identify areas and species of conservation importance.

Behavioural isolation When courtship rituals (breeding calls, mating dances etc.) between two species vary, such as in the Birds of Paradise.

Belt transect A band of chosen width (usually 0.5–1 m) along an environmental gradient.

Bioaccumulation The build up of non-biodegradable or slowly biodegradable chemicals in the body.

Biological hotspot An area with a significant amount of biodiversity.

Biomagnification The process whereby the concentration of a chemical substance increases at each trophic level.

Biotic The living part of an ecosystem, i.e. the **community**.

Buffering capacity The ability of some environments to neutralise the affects of acid rain, especially chalk and limestone.

Buffer zones Habitats that are either managed or undisturbed, and minimise disturbance in the protected area from outside influences such as people, agriculture, pests and diseases.

Captive breeding The process of breeding animals outside of their natural environment in controlled environments such as zoos.

Carnivore An organism that only eats animals.

Chemoautotrophs Organisms that use chemical energy from oxidation reactions to create glucose (e.g. nitrifying bacteria).

CITES (Convention on the International Trade in Endangered Species) An international agreement aimed at preventing trade in endangered species of plants and animals.

Collision plate margin Location where tectonic plates collide.

Conference of the Parties (CoP) Regular meetings of governments to assess the success and future directions of the **UNCBD** or **UNFCCC**.

Constructive plate margin Location where tectonic plates move apart.

Consumer An organism that eats other organisms to obtain its food.

Continuous transect An area where the whole transect is sampled (in either a belt or a line through the habitat).

Cornucopian A technocentric viewpoint that believes that continued progress and provision of material items for humanity can be met by continued advances in technology.

Cultural services Services provided by ecosystems that provide opportunities for outdoor recreation, education, spiritual well-being and improvements to human health.

Daisyworld A model developed by James Lovelock to show how the Gaia hypothesis could regulate life on Earth. It is a simple model for a worldwide ecosystem.

Deamination The breakdown of organic nitrogen (e.g. amino acids) into ammonia. Carried out by, for example, decomposers.

Decomposer An organism that obtains its food from the breakdown of dead organic matter.

Deep ecology An ecocentric viewpoint that sees humans as subject to nature and not in control of it.

Denitrifying bacteria Bacteria that convert nitrates into nitrogen.

Density-dependent factors Limiting factors that are related to population density. They are biotic factors (e.g. competition for resources; space) that limit population growth.

Density-independent factors Factors that are abiotic and do not depend on the size of the population.

Destructive plate margin Location where tectonic plates move together.

Dichotomous key A guide that is used to identify species. The key is organised into steps, with two options containing contrasting features of species given at each step.

DNA A molecule containing the genetic information that codes for the structure and characteristics of an organism.

Dry deposition The direct deposition of particulates of SO_2 and NO_2. It

typically occurs close to the source of emission and causes damage to buildings and structures.

Dry weight biomass Where water is removed before biomass is measured.

Ecocentrism A nature-centred environmental philosophy.

Ecological efficiency The percentage of energy transferred from one trophic level to the next.

Ecological gradient Found where two ecosystems meet or where an ecosystem ends.

Eluviation The removal of material down a soil through solution and suspension.

Environmental impact statement Report produced by an **environmental impact assessment**.

Environmental isolation When the geographic ranges of two species overlap, but their niches differ enough to cause reproductive isolation.

Environmental manager An **anthropogenic** viewpoint that believes that humans should manage natural systems for economic profit.

Environmental philosophy World view determined by an **environmental value system**.

Exponential Increasingly rapid growth.

Ex situ conservation The conservation of species away from their natural habitat in carefully controlled environments such as zoos.

Extrapolation Estimating values beyond measured values, using graphs or other techniques.

Flows Movement through a system in the form of inputs and outputs. Can be either transfers or transformations.

Food miles The distance a food travels to its final destination.

Food web A diagram that shows interconnected food chains in an ecosystem.

Formal sector (economy) Part of the economy that is regulated, taxed and subject to working conditions.

Frame quadrat An empty square frame of known area (e.g. $1\,m^2$).

Freshwater Rivers, lakes and groundwater. Does not contain salt.

Fungi Organisms that are heterotrophic and have cell walls made of chitin.

Gametic isolation When sperm and ova are incompatible, and will not allow fertilisation to take place.

Gene Section of DNA that codes for a particular characteristic in a species.

Gene pool All the different genes in a population.

Genetically modified species Species into which new genes have been introduced from other organisms.

Global dimming A reduction in global temperatures as a result of pollution.

Goods Products produced by ecosystems – for example, food, fibre, fuel (peat, wood and non-woody biomass) and water from aquifers, rivers and lakes.

Green politics An ideology that places central importance on ecological and environmental goals, and on sustainable development.

Green Revolution The application of science and technology to agriculture – for example, high-yielding varieties, breeding programmes, widespread use of chemical fertilisers and pesticides, irrigation.

Grid quadrat A square frame divided into 100 small squares.

Groundwater Water that is found beneath the Earth's surface in aquifers.

Herbivore An organism that only eats plants.

Herbivory The process of an organism feeding on a plant.

Heterotroph Organisms that obtain the energy, minerals and nutrients they need by eating other organisms.

Holistic Studying a system as a whole, with patterns and processes described for the whole system.

Humification, degradation and **mineralisation** The process whereby organic matter is broken down and the nutrients are returned to the soil. The breakdown releases organic acids, chelating agents, which break down clay to silica and soluble iron and aluminium.

Humus Partially decomposed organic matter derived from the decay of dead plants and animals in soils.

Hydrological cycle The cycle of water between the atmosphere, lithosphere and biosphere.

Illuviation The redeposition of material in the lower horizons.

Indicator species A species whose presence, absence or abundance can be used as an indication of pollution.

Inertia The resistance of an ecosystem to being altered.

Informal sector (economy) Part of the economy that is unregulated, untaxed and not subject to working conditions – it is sometimes referred to as the 'black market'.

In situ conservation The conservation of species in their natural habitat.

Intergovernmental organisations (IGOs) Organisations that are established through international agreements. They bring governments together to work to protect the Earth's natural resources – for example, UNEP.

International Union for Conservation of Nature (IUCN) The world's oldest and largest global environmental organisation. Its aim is to show how biodiversity is fundamental to addressing climate change, sustainable development and food security.

Interrupted transect When samples are taken at points of equal distance along a transect.

Interspecific competition Competition between members of *different* species.

Intraspecific competition Competition between members of the *same* species.

Invasive species Introduction of non-native species.

Island biogeography theory Predicts that smaller islands of habitat will contain fewer species than larger islands.

Johannesburg World Summit on Sustainable Development International meeting 10 years after the Rio Earth Summit. It mainly addressed social issues with targets set to reduce poverty and increase access to safe drinking water and sanitation.

J-population curve Population growth curve that shows exponential growth. Growth is initially slow, then increasingly rapid, and does not slow down.

Kyoto Protocol An agreement built on the Earth Summit's **Climate Change Convention**. It was developed at a UN meeting in Kyoto, and agreed to reduce greenhouse gas emissions from 1990 levels.

Leaching The removal of soluble material in solution.

Lessivage The removal in suspension of fine particles of clay.

Limiting factor Restricts the growth of a population or prevents it from increasing further.

Line transect When a tape measure is laid out in the direction of an **environmental gradient** – all organisms touching the tape are recorded.

Lithosphere The upper mantle of the Earth, which is divided into many plates that move over the **magma**.

Logarithmic scale Axis on a graph where the increase is not linear but 1, 10, 100, etc.

Magma The molten part of the Earth's mantle.

Marine Relating to the sea/saltwater.

Mass extinction An event in which at least 75% of the species on Earth disappear within a geologically short time period, usually between a few hundred thousand to a few million years.

Mechanical isolation When physical differences in, for example, reproductive organs prevent mating or pollination.

Monoculture A crop of only one species.

Mutualism An interaction in which both species derive benefit.

Nitrifying bacteria Bacteria that convert ammonium ions into nitrite and then nitrate.

Nitrogen-fixing bacteria Bacteria that convert nitrogen from the atmosphere into ammonium ions.

Non-governmental organisations (NGOs) Organisations that are not run by, funded by, or influenced by governments of any country – for example Greenpeace, the World Wide Fund for Nature (WWF).

Non-technical summary Report designed for the general public at the end of an **environmental impact assessment**.

Omnivore An organism that eats both plants and animals.

Overhunting Hunting at unsustainable levels.

Parasitism A relationship in which one organism – the **parasite** – benefits at the expense of another – the **host** – from which it derives its food.

Parent material The rock and mineral regolith from which soil develops.

Percentage cover The proportion of a quadrat covered by a species, measured as a percentage. It is worked out for each species present.

Percentage frequency The percentage of quadrats in an area in which at least one individual of a species is found.

Persistent organic pollutants (POPs) Chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment.

Pesticides Chemicals that kill insect pests.

Photoautotrophs Organisms that convert sunlight energy into chemical energy (e.g. all plants).

Photosynthesis The transformation of light energy into the chemical energy of organic matter.

Pioneer species Species in the first stage of an ecological succession. They are hardy species able to withstand difficult conditions.

Plagioclimax Where disturbance stops the process of succession so that a climax community is not reached.

Point quadrat A frame with 10 holes, inserted into the ground by a leg, and used for sampling vegetation that grows in layers.

Population crash A sudden decrease in a population.

Population density The number of individuals of each species per unit area. It is calculated by dividing the number of organisms by the total area of the quadrats.

Population momentum An increase in the size of a population despite a fall in the birth rate. This is because of a large proportion of the population entering the reproductive years.

Predation When one animal (or sometimes a plant) eats another animal.

Primary consumer The first trophic level in a food chain, i.e. **herbivores**.

Primary succession The formation of an ecosystem from, for example, bare rock.

Producer An organism that makes its own food (i.e. glucose) – for example, plants and some bacteria.

Production:respiration (P:R) ratio A measure of productivity relative to respiration.

Pro-natalist population policy A policy that is in favour of more births.

Protected areas Conservation areas that aim to preserve the greatest amount of natural habitat within an ecosystem.

Pyramid of biomass Diagram showing the biological mass at each trophic level in a food chain.

Pyramid of numbers Diagram showing the number of organisms (producers and consumers) coexisting in an ecosystem.

Pyramid of productivity Diagram showing the flow of energy

through trophic levels and always showing a decrease in energy along the food chain. It is the only pyramid that is *always* pyramid shaped.

Quadrat Used for estimating the abundance of plants and non-mobile animals.

Quantitative Measured by quantity, i.e. information that can be counted or expressed numerically.

Random sampling Used if the same habitat is found throughout the area.

Red List Produced by the **IUCN**, an assessment of the conservation status of species on a global scale.

Reductionist dividing a system into parts, or components, which can each be studied separately.

Regolith The irregular cover of loose rock debris that covers the Earth.

Regulatory services Ecosystem services essential for, for example, pollination, regulation of pests and diseases, climate regulation, flood regulation, water quality regulation, erosion control.

Reintroduction programmes Where animals raised or rehabilitated in, for example, zoos or aquariums are released into their natural habitats.

Resilience The ability of an ecosystem to recover after disturbance.

Respiration The breakdown of glucose using oxygen, releasing carbon dioxide, water and energy.

Rio Earth Summit The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992.

Secondary consumer The third trophic level in a food chain. Secondary consumers are either **omnivores** or **carnivores**.

Secondary succession Succession in an area that already has soil.

Self-reliant soft ecology An **anthropogenic** viewpoint that believes that communities should play an active role in environmental issues.

Simpson's index A measurement of species diversity.

Sixth mass extinction A mass extinction caused by human activities (i.e. biotic causes).

Social system The people in a society considered as a system organised by a characteristic pattern of relationships.

Soil A mixture of mineral particles and organic material that covers the land, and in which terrestrial plants grow.

Soil degradation The decline in quantity and quality of soil.

Soil fertility The ability of a soil to provide the nutrients needed for plant growth.

Soil horizons Layers within a soil that vary in terms of texture, structure, colour, pH and mineral content.

Soil profile A vertical section through a soil, from the surface down to the parent material, revealing the soil layers or horizons.

Soil structure Relating to the shape of soil particles.

Soil texture Relating to the size of soil particles.

Species-based approach to conservation An approach that focuses on vulnerable species and in raising their profile.

S-population curve Population growth curve that shows an initial rapid growth (exponential growth) and then slows down as the carrying capacity is reached.

Stockholm Declaration Statement produced by the UN Conference on the Human Environment (Stockholm, 1972), which played an essential role in setting targets and promoting action concerning sustainable development at both local and international levels.

Storages The stocks or reservoirs of energy and matter in a system.

Stratified random sampling Used in two areas different in habitat quality.

Support services Ecosystem services essentials for life, including primary productivity, soil formation and the cycling of nutrients.

Survivorship curves Graphs that plot the number of offspring surviving in a population over time.

Systematic sampling Used along a **transect** where there is an environmental gradient.

Technocentrism A technology-centred environmental philosophy.

Temporal isolation When two species, whose ranges overlap, are active at different times.

Terrestrial Relating to the land.

Tertiary consumer The fourth trophic level in a food chain.

Theory of evolution by natural selection Charles Darwin's explanation of how the Earth's biodiversity has arisen.

Transect Used to measure changes along an **environmental gradient**, ensuring all parts of the gradient are measured.

Transfer A process involving a change in location within the system but no change in state – for example, water flowing from groundwater into a river.

Transformation Leads to the formation of new products – for example, photosynthesis that converts sunlight energy, carbon dioxide and water into glucose and oxygen – or involves a change in state, such as water evaporating from a leaf into the atmosphere.

UN Convention on Biological Diversity (UNCBD) International legally binding agreement developed at the **Rio Earth Summit**. It has three main goals: conservation of biodiversity, the sustainable use of its components, and fair and equitable sharing of benefits arising from genetic resources.

UN Framework Convention on Climate Change (UNFCCC) International, legally binding agreement developed at the **Rio Earth Summit**. Its objective

is to stabilise greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system.

Virtual water Water that is used to produce crops or flowers, and then the product is exported (often from LEDCs to MEDCs).

Wet deposition SO_2 and NO_2 dissolved in precipitation, leading to an increase in acidification of precipitation and sometimes falling at great distances from the source.

World Conservation Strategy (WCS) International agreement that prioritised the maintenance of essential life support systems, the preservation of genetic diversity, and the need to use species and ecosystems in a sustainable way.