FOR THE
IB DIPLOMA

Internal Assessment for Environmental Systems and Societies

Skills for Success

Andrew Davis
Garrett Nagle

HODDER EDUCATION

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Dedication

For my mother, Mary Davis, with love (AD)

To Angela, Rosie, Patrick and Bethany (GN)

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ISBN: 978 1 5104 5823 9

First published in 2019 by

Hodder Education,

An Hachette UK Company

Carmelite House

50 Victoria Embankment

London EC4Y 0DZ

www.hoddereducation.com

Impression number 10 9 8 7 6 5 4 3 2 1

Year 2023 2022 2021 2020 2019

Cover photo © SasinTipchai/Shutterstock

Illustrations by Aptara Inc.

Typeset in GoudyStd 10/12 pts by Aptara Inc.

Printed in Spain

A catalogue record for this title is available from the British Library.

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Contents

Introduction

How to use this book

There are two aspects to the investigative work in the IB ESS programme: general practical work and a single individual investigation – the internal assessment project (IA).

This publication is aimed specifically at IB ESS students and is to be used throughout your two years of study. Practical activities and the IA form an essential part of the 2015 IB ESS syllabus (first assessment held in 2017) which forms 30 hours of recommended teaching time (20 hours of practical activities and 10 hours for the IA). This represents an average 20% of the total teaching time. The internal assessment is worth 25% of the total marks available for ESS in the final assessment.

General practical work includes laboratory projects, ecological fieldwork studies, computer simulations, using databases for studying and analysing secondary data, data-analysis exercises, developing and using models, questionnaires and surveys, demonstrations by your ESS teacher and class activities which will be of a formative nature. These are designed to help you learn ESS via practical work. The range of tasks you undertake will reflect the interdisciplinary nature of the course.

This guide will ensure you can aim for your best grade by:

- building practical and analytical skills for investigations through a comprehensive range of strategies and detailed examiner advice and expert tips
- offering concise, clear explanations of all the IB requirements, such as the assessment objectives of each assessment criterion for the IA, including checklists and rules on academic honesty
- demonstrating what is required to obtain the best IA grade for the individual investigation with advice and tips, including common mistakes to avoid
- suggesting investigations that might, if modified, form the basis of an individual investigation
- making explicit reference to the IB learner profile and the associated approaches to learning (ATLs) that are central to the IB programme, with their connections to practical work
- providing infographics at the beginning of each section which visually display essential information
- including exemplars and worked answers and commentary throughout so you can see the application of ESS principles and concepts
- testing your comprehension of the skills covered with embedded activity questions.

Features of this book

Key definition

The definitions of essential key terms are provided on the page where they appear. These are words that you can be expected to know for exams and practical work. A glossary of other essential terms, highlighted throughout the text, is given at the end of the book.

Examiner guidance

These tips give you advice that is likely to be in line with IB examiners.

Expert tip

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

Common mistake

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

Worked examples

Some investigative skills require you to carry out mathematical calculations, plot graphs, and so on. These examples show you how.

ACTIVITY

Suggested outline of possible practice activities, incorporating appropriate IB command terms.

Ideas for investigations

Ideas for possible investigations.

ENVIRONMENTAL ISSUES

Ideas about how investigations can link to key environmental issues.

Author profiles

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Andrew teaches IB Diploma Environmental Systems and Societies (ESS) and Biology at St Edward's School, Oxford. He is an IB examiner and the author of several textbooks for the IB, including *Environmental Systems and Societies for the IB Diploma Study and Revision Guide*, *Biology for the IB Diploma Study and Revision Guide*, *Internal Assessment for Biology: Skills for Success*, and *Biology for the IB MYP 4 & 5: By concept*. He is also author of the following online teaching and learning resources: *Biology for the IB Diploma* and *Biology for the IB MYP 4 & 5*.

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Authors' acknowledgements

Our thanks to Christopher Talbot, formerly of Anglo-Chinese School (Independent) Singapore, who freely provided material and substantial input including rigorous editing which significantly improved the text – we are extremely grateful to him for providing such tremendous support and encouragement throughout the process. We also wish to thank Dr David Fairley of Overseas Family School, Singapore, who provided invaluable feedback on all chapters of the book, and provided the section on coding – his input is greatly appreciated.

Studying IB Environmental

IB learner profile

The IB ESS course is linked to the IB learner profile. Throughout the course, and while carrying out your internal assessment, you will have the opportunity to develop each aspect of the learner profile: Inquirers, Knowledgeable, Thinkers, Communicators, Principled, Open-minded, Caring, Risk-takers, Balanced and Reflective.

Studying IB ESS

Investigations

Carrying out research activities throughout your ESS course, both environmental and societal in nature, will give you the skills you need for your internal assessment.

Systems and Societies (ESS)

Approaches to Learning

The IB ESS course, and the internal assessment in particular, give you the chance to develop the approaches to learning skills:

- thinking skills when planning investigations, collecting data and analysing your results
- social skills when working with your peers
- communication skills when reporting and presenting your findings
- self-management skills when working independently
- research skills to help plan your investigation, and to put it into context.

Internal assessment

The internal assessment gives you the opportunity to display the skills and knowledge you have learned throughout your course, while exploring an ESS topic and environmental issue that interest you personally.

Studying IB Environmental Systems and Societies

Framework for ESS

Your IB ESS syllabus is comprehensive and detailed. It helps to simplify the content by using a 'concept tree' (Figure 1), which outlines the essential components of your course and how they interrelate. The concepts listed in Figure 1 are discussed on pages 4–5. The investigative skills you will be learning during the course can be framed in the context of this figure. Subsequent chapters discuss the different topics covered by the ESS syllabus and essential skills that you need to succeed in practical work and the IA.

Figure 1 can also be used to help you decide the area of ESS you want to address in your internal assessment project (Chapters 12 and 13).

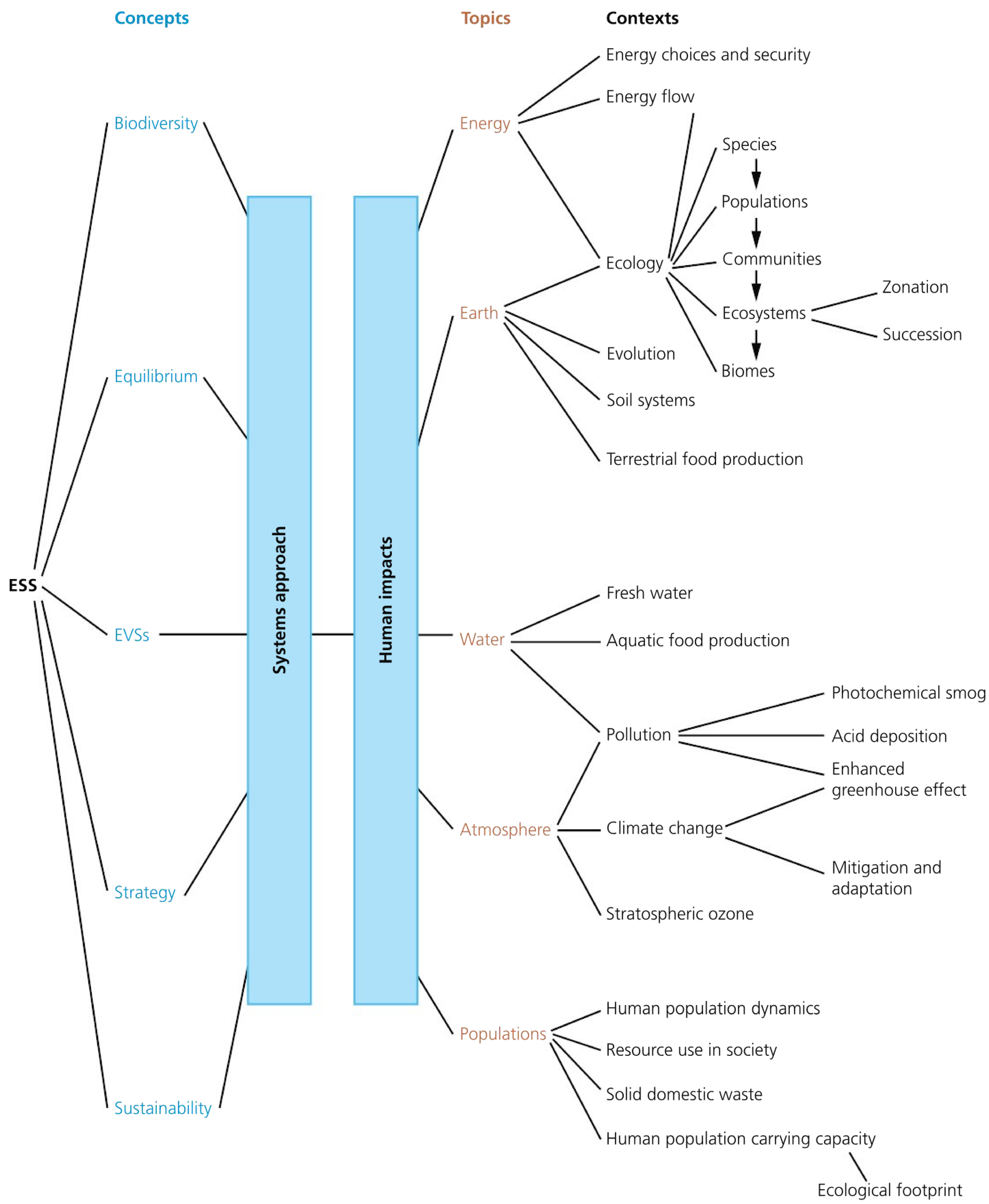


Figure 1 ESS concept tree; EVSs = environmental value systems (page 4)

The investigation cycle

Investigations are carried out using both observations and research. Observations result in hypotheses, which can lead to experiments that manipulate a variable in order to see its effect, which in turn result in an improved understanding of the issue being researched. Alternatively, an investigation may simply observe and analyse the effect of one variable on another (for example, using questionnaires to investigate the effect of one aspect of population demographics, such as age, on attitudes to a specific environmental issue). This process can be seen as a cycle (Figure 2 and Table 1). Exploration of one idea can lead to further modification, through reflection and evaluation, resulting in the investigation of further hypotheses.

Key definition

Investigation a study consisting of a controlled experiment in the laboratory or field-based studies involving sampling.

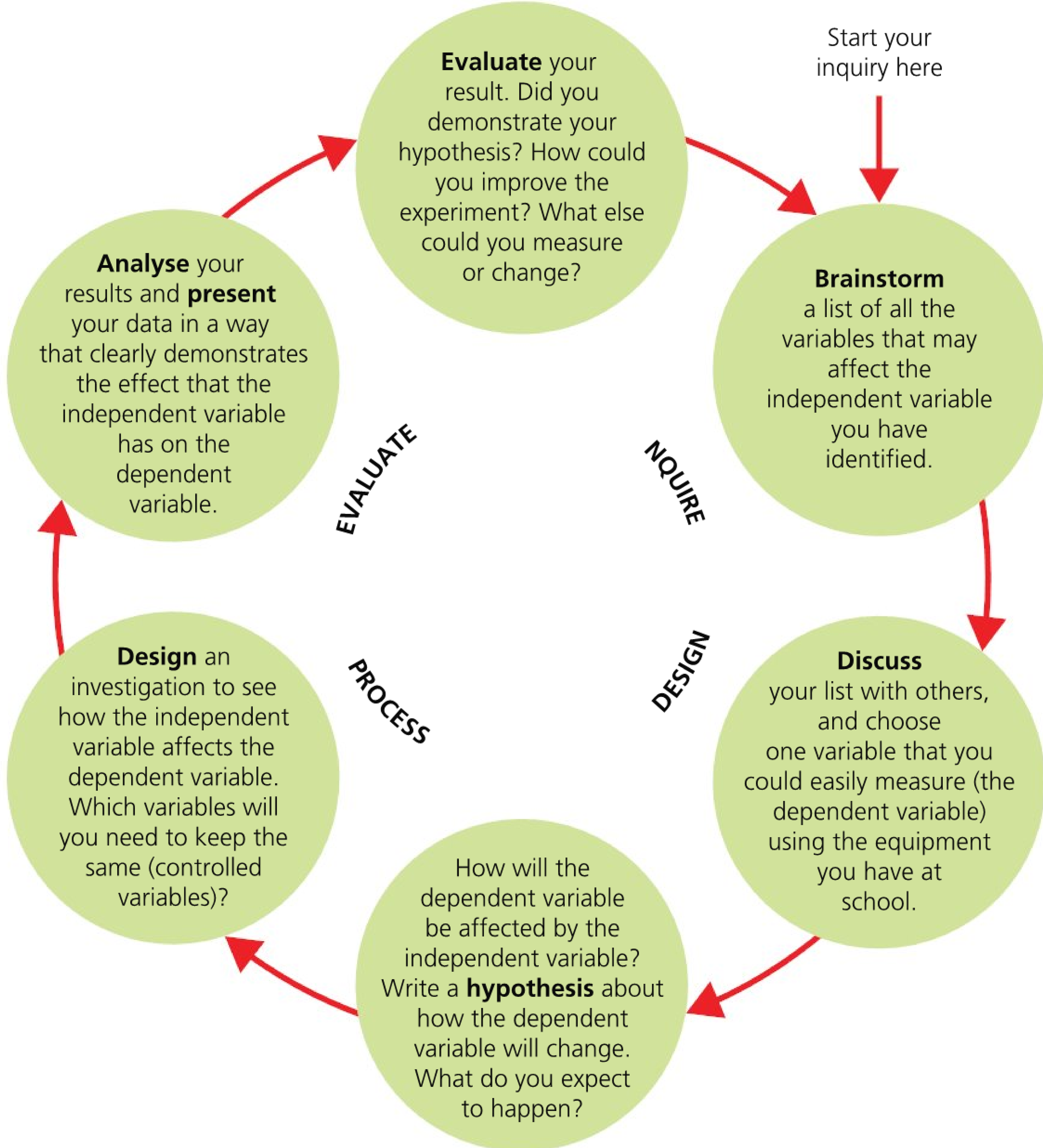


Figure 2 The investigation cycle

Stage of cycle	Description	Key word definitions
1	Formulate your research question: this usually inquires how one **variable** (the **independent variable**) affects another (the **dependent variable**	**Variable** – a factor that is being changed, measured, or kept the same in an investigation. **Independent variable** – the variable that is being changed in an investigation. **Dependent variable** – the variable that is being measured in an investigation. **Processed variable** – a variable that can be produced by transforming a measured variable through mathematical manipulation (see Expert tip box on page xi).
2	The research question may lead to the development of a **hypothesis**. When making a hypothesis, the investigator proposes how the independent variable may affect the dependent variable. A **prediction** may be made.	**Hypothesis** – a tentative explanation of an observed phenomenon or event that can be investigated using the scientific method. **Prediction/predict** – give an expected result.
3	So that a **correlation** between the two variables (independent and dependent) can be established, other variables must be kept the same – these are called **controlled variables**	**Controlled variables** – these variables are kept the same in an investigation. In an experiment, at least three controlled variables should be listed, and information about how they will be kept the same included.
4	Develop a method and outline it clearly. Materials should be listed. Sizes, volumes and other appropriate information should also be included such as ± measurement uncertainties (see pages 162–164). One variable should be manipulated and one measured; all other variables should be **controlled** The method should be written in the passive voice and in sufficient detail and clarity so that someone else can follow the instructions.	**Controlled** – method that uses controlled variables and suitable **controls**, if appropriate. **Control** – an experiment where the independent variable is either kept constant or removed. This can be used for comparison, to prove that any changes in the dependent variable in experiments when the independent variable is manipulated must be due to the independent variable rather than other factors.
5	Carry out your investigation and gather **data**. Record your data by **measuring** the dependent variable. Present your data with their appropriate units. Process your data in some way, for example, mean values calculated or a line of best fit drawn. Plot a graph to present the results in a way that displays them clearly and helps interpretation. Qualitative data (observations) may also be recorded (see Expert tip box on page xi).	**Data** – recorded products of observations and measurements. **Measuring/measure** – obtain a value for a quantity.
6	Following an **analysis**, develop an **explanation** for the results. What do the results show? Describe and explain the results. Do the results support the hypothesis, or not?	**Analysis/analyse** – break down in order to bring out the essential elements or structure. **Explanation/explain** – give a detailed account including reasons or causes.
7	**Evaluate** the investigation and suggest improvements. When commenting on limitations, consider the procedures, the equipment, the use of equipment, the quality of the data (for example, its **accuracy** and **precision** – see Figure 3) and the relevance of the data. To what extent may the limitations have affected the results? Propose realistic improvements that address the limitations. The **sensitivity** of the equipment used must also be taken into account.	**Evaluate/evaluation** – make an appraisal by weighing up the strengths and limitations. **Accuracy** – how close to the true value a result is. **Precision** – describes the reproducibility of repeated measurements of the same quantity and how close they are to each other. Note, measurements can be precise but not accurate (see Figure 3). **Sensitivity** – the number of significant digits to which a value can be reliably measured. For example, if a digital thermometer can measure to two decimal places, this is the sensitivity of data that can be recorded.
8	The improvements to the method can lead to further investigations, and so the cycle repeats itself.	

Table 1 The investigation cycle

Replicates can improve the reliability of an investigation and enable anomalies to be identified.

Due to the complexities of systems, other variables besides the independent variable may affect the dependent variable. These **confounding variables** must be held constant if possible, or at least monitored so that their effect on the results can be accounted for in the analysis.

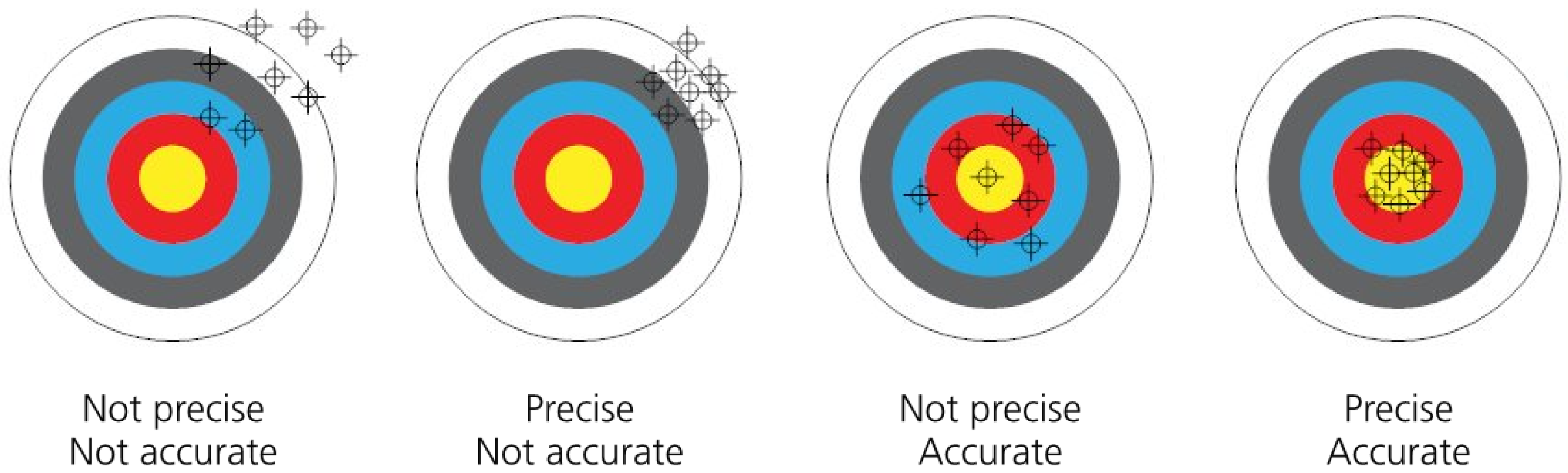


Figure 3 Accuracy versus precision

Quantitative data are numerical data (with associated units and uncertainty, if appropriate – some measurements such as species richness do not have units). An example of such data might be measurements of the breadth of leaves from a species of plant grown in shaded and exposed positions, or the pH values of topsoil samples in different positions within tropical primary rainforest.

Quantitative data may be discontinuous (discrete) or continuous. Discontinuous data cannot be measured across a complete range, and are either numerical or categorical.

- Numerical data can only take certain values (for example, whole numbers), such as the number of petals present in a species of flower or number of fruit flies on an apple.
- Categorical data is where a measured variable falls into a number of distinct categories based on specific features, such as male or female, or a country's level of economic development.

Continuous data can take any value over a range, for example, temperature, mass, distance and time.

In addition, data may be primary or secondary. **Primary data** is the actual data you measured and may include associated qualitative data (observations). It is acceptable for you to convert handwritten raw data into word-processed form. **Secondary data** is data obtained from literature. Such data must be clearly referenced to show its source, for example:

	Release rate of methyl salicylate (mg per plot day^{-1})			
	0	**5**	**50**	**100**
Aphid population	2810	2073	1503	1426
Percentage reduction		26	47	49

Source: Reproduced from Developing sustainable pest control from chemical ecology, *Agriculture, Ecosystems and Environment* 64 (1997), 149–156 Published by Elsevier

Table 2 Reduction of cereal aphid populations in spring-sown wheat using methyl salicylate (total numbers of aphids: *Rhopalosiphum padi* and *Sitobion avenae*). Data otherwise unpublished

Key definitions

Replicate – a repeating of the entire experiment run at the same time.

Confounding variables
any other variable, besides the independent variable, that also has an effect on the dependent variable.

Expert tip

In ESS investigations, observations are recorded as data (singular datum). You will collect two types of data during your ESS investigation:
quantitative **qualitative**

Qualitative data are observations not involving measurements, such as those recorded in an ecological study to note conditions in a survey area (for example, factors that may make the collection site typical or atypical, such as cloud cover or rainfall during the collecting of abiotic data).

Quantitative data are numerical data from measurements, such as measurements taken when recording a dependent variable (for example, the species richness recorded in a biodiversity study).

Expert tip

Raw data refers to data collected without any processing, and are just the values of each variable collected. It is often difficult to use for data analysis, and usually needs to be processed in some way.

Processed data refers to data that are ready for analysis. Processing involves carrying out a calculation, for example, in a study investigating the effect of acid on the rate of germination, the germination percentage first needs to be calculated (seeds germinated/total seeds × 100). The germination rate is then determined by calculating the productivity (page 11) at different time intervals after planting and then plotting these data.

A **processed variable** refers to a variable that is calculated from measured data (that is, from the dependent variable), for example, in an investigation looking at the effect of human disturbance on biodiversity, the dependent variables will be the number and relative abundance of different species; the processed variable calculated from this will be species diversity using the Simpson diversity index.

During your two-year IB ESS course you will carry out practical work to help ground your understanding of the subject. This work may be lab-based or located in an environment outside your school or college. This work will help you to understand some of the ESS concepts, teach you important practical and analytical skills, and give you opportunities to extend your knowledge through your own investigations.

Approaches to learning

Approaches to learning (ATL) are deliberate strategies, skills and attitudes which underlie all aspects of the IB Diploma Programme. These approaches are intrinsically linked with the IB learner profile attributes (see below), and are designed to enhance your learning and preparation for the Diploma Programme assessment and beyond.

Expert tip

ATLs encompass the key values and principles that underpin an IB education.

The aims of ATLs in the IB Diploma Programme are to:

- link prior knowledge to course-specific understandings, and make connections between different subjects
- encourage you to develop a variety of skills that will equip you to continue to be actively engaged in learning after you leave your school or college
- help you not only obtain university admission through better grades but also prepare for success during tertiary education and beyond
- enhance further the coherence and relevance of your IB Diploma Programme experience.

The five approaches to learning develop the following skills:

- thinking skills
- social skills
- communication skills
- self-management skills
- research skills.

Practical activities clearly allow you to interact directly with natural phenomena, explore a topic and examine specific research questions. All practical skills covered in this book can be viewed in the context of ATLs. They also give you the opportunity to develop and use IB terminology:

- research skills to find out appropriate methods to investigate specific research questions, and put your investigation in the context of the wider community
- thinking skills to design investigations, collect and analyse data, and then evaluate your results
- social skills in order to collaborate with peers
- communication skills to effectively and concisely present your findings
- self-management skills to make sure you successfully plan your time and meet deadlines.

The IB learner profile

The IB ESS course is closely linked with the IB learner profile (Table 3). By following the course, you will have engaged with all attributes of the IB learner profile: the requirements of the IA provide opportunities for you to develop every aspect of the profile.

Examiner guidance

Be aware that a strong **correlation** does not necessarily mean causation. In other words, you cannot state definitely that X causes the changes in Y (where X is a dependent variable and Y is an independent variable).

You may of course suggest in your conclusion that X causes changes in Y, or *vice versa*. However, you should not draw definite cause and effect conclusions based on correlation.

There are several reasons why you cannot make definite causal statements:

- You do not know the direction of the cause – does X cause Y, or does Y cause X?
- A third variable Z may be involved that is responsible for the correlation between X and Y.
- The apparent relationship may simply be due to chance.

Key definition

Correlation when one variable changes with another variable, so there is a relation between them. The strength of a correlation can be measured using a correlation coefficient. A correlation need not be a causal relation.

Learner profile attribute	Relevance to ESS syllabus
Inquirers	Practical work and internal assessment
Knowledgeable	Links to international-mindedness Practical work and internal assessment
Thinkers	Links to theory of knowledge Practical work and internal assessment
Communicators	External assessment (examinations) Practical work and internal assessment
Principled	Practical work and internal assessment Ethical behaviour Academic honesty
Open-minded	Links to international-mindedness Practical work and internal assessment The group 4 project (optional for ESS students)
Caring	Practical work and internal assessment The group 4 project (optional for ESS students) Ethical behaviour
Risk-takers	Practical work and internal assessment The group 4 project (optional for ESS students)
Balanced	Practical work and internal assessment The group 4 project (optional for ESS students) Fieldwork
Reflective	Practical work and internal assessment The group 4 project (optional for ESS students)

Table 3 Relevance of the IB learner profile to the IB ESS syllabus

The internal assessment

The internal assessment (IA) forms 25% of your final mark with the external examinations (Papers 1 and 2) forming 75% of your final assessment.

The IA criteria are designed to assess the different aspects of your study. Each criterion aims to assess different aspects of your research abilities. The sections are differently weighted to emphasize the relative contribution of each aspect to the overall quality of the investigation.

Criterion	Identifying the context	Planning	Results, analysis and conclusion	Discussion and evaluation	Applications	Communication	Total marks available
Marks available	6	6	6	6	3	3	30

Table 4 Marking criteria for the ESS IA

The IA will involve 10 hours of work and will generate a word-processed report or write-up between 1 500 and 2 250 words long.

This will be marked out of a maximum of 30 marks based upon the 6 assessment criteria (Table 4). This will then be scaled to a mark out of 25. Your individual investigation will be internally marked by your IB ESS teacher but moderated externally (re-marked) by an experienced IB ESS teacher appointed by the IBO. External moderators will not read beyond 2 250 words and will only allocate marks up to this limit.

There are separate chapters for each of the IA criteria in this guide (Chapters 12–17). Checklists at the end of each chapter will help you to ensure that your report matches the requirements of the ESS assessment criteria.

Grade boundaries for the IA are as follows (using data from May 2017, November 2017 and May 2018 examinations):

Grade	1	2	3	4	5	6	7
Mark range	0–4	5–8	9–13	14–16	17–20	21–23	24–30

Table 5 Grade boundaries for the ESS IA

Planning an IA

The IA requires you to carry out an individual investigation of an ESS research question. The research question and investigation need to be designed and implemented by you, individually. The investigation is submitted as a written report.

The investigation needs to address specific assessment criteria. The ESS IA has six criteria that need to be covered by your report (see Table 4 on page xiii) **Note: these criteria are different from other group 4 sciences and are unique to ESS.** Please also note, if you carry out an ESS extended essay, it cannot be based on the research question of the ESS internal assessment.

The IA engages in a study of an environmental issue that can be focused within the scope of the ESS internal assessment. At the same time, it must be linked to a broader environmental context that will ultimately inform the wider issue through the suggestion of solutions or 'applications'. The process of engaging with this involves:

- identifying a broad environmental issue that interests you
- developing and carrying out a small-scale study that relates to one or more aspects of this environmental issue, that is, putting the issue into context
- suggesting a solution to the issue highlighted by your study, relating this back to the broader issue using the conclusion and evaluation of your investigation.

While the research question should focus on one particular issue that can be addressed through your own research, your research must also be applicable to a wider context, and its conclusion must offer potential solutions to broader problems.

You should explore a range of options available to you and pursue a research question that engages your interest. You should decide whether to do an individual investigation that involves the use of surveys, case studies, ecological fieldwork, hands-on practical laboratory work, the use of secondary sources such as databases and simulations, or possibly a mix of these sources.

Table 6 below gives a suggested outline for the stages involved in organizing the IA investigation, with route-point markers that are linked to the assessment criteria. The two routes presented divide the type of study into either environmental or societal in nature, although the possibility of a research question that involves a hybrid type of study should not be ruled out.

Expert tip

In your IA you will identify a global issue, carry out a related study on a local scale, and then consider how your findings provide solutions to the bigger issue.

The small-scale study of one aspect of that global problem can use secondary data, available through databases, or other secondary sources.

Environmental systems	**Inquiry route-point marker**	**Societies**
	Planning phase	
Develop a research question which addresses an issue or problem arising from the interaction of people and their environments.	**Identifying the context:** Raising awareness and understanding of the issue, question or problem.	Develop a research question which addresses the values, attitudes and activities of the different groups of individuals regarding this issue, question or problem.
Set up the research question and suggest hypotheses, where this is applicable.	**Planning focus:** Definition and description of the issue and research question.	Identify interested groups. Classify values and activities.
Describe methods and techniques. Decide on what sort of data or information to collect. Measuring, counting, field sketching of photographs, mapping, sampling programme, equipment.	**Planning:** Design of research.	Describe methods and techniques. Questionnaires, surveys, case studies, opinion polls, bipolar scales, interviews, prompts (for example, photographs, media analysis).

Environmental systems	Inquiry route-point marker	Societies
	Collecting information	
Graphs, pie charts, flow charts, tables, maps, descriptive statistics, inferential statistics, hypothesis testing. What does the data show?	**Results, analysis and conclusion:** Data analysis and presentation.	Identify bias, prejudice, and misrepresentation. Identify conflicts of interest and the most powerful positions. What does the data show?
Evaluation of methods. What changes are likely to happen in the future? On what timescale? How reliable are your predictions? What does research show?	**Discussion and evaluation:** Discuss, predict, evaluate.	Evaluation of methods. Which viewpoint is likely to succeed? Can compromise be reached? Evaluate the sustainability issues resulting from the inquiry.
Based on the environmental context, what are the management options? Which should be carried out? Does the social consideration conflict with the environmental one?	**Application:** Solutions and decisions.	Based on the social context, what are the management options? Which ones should or could be carried out? Why? Will the inquiry change your ideas, ethics or behaviour?

Table 6 Different routes to carrying out the IA

Your school may require you to complete a preliminary IA proposal. This may mean that you need to suggest a research question and methodology, carry out a risk assessment and complete a requisition for apparatus and biological materials for preliminary work, if carrying out a lab-based project.

■ Setting up a schedule

It may also be helpful to set up a timeline with start dates and deadlines for each part of your individual investigation, if your school has not done that. A sample timeline is shown below in Table 7.

	Start date	Task	Deadline date
Planning 1		Read Chapters 12 and 13 in this guide.	
Planning 2		Decide on an environmental issue, research question, methodology (including statistical test, if appropriate) and outline data-collection methods.	
Planning 3		Prepare a risk assessment and show your teacher the completed risk assessment form. Prepare an environmental assessment.	
Planning 4		Check and organize that the apparatus, instruments, chemicals and biological materials will be available in your school laboratory.	
Practical		Complete the investigative work and collect raw data in the time allocated. Allow time to carry out duplicates, extend the range of data collected, and for preliminary work. Document any alterations to your plan as soon as they occur and, if necessary, make alterations to the supporting theory.	
Report 1		Hand in the first draft and consult with your teacher.	
Report 2		Submit the final draft after an online plagiarism check.	

Table 7 An example internal assessment timeline

ESS concepts and

practical skills

1 ESS skills and concepts

Key concepts

The ESS syllabus is underpinned by the following central concepts:

- Environmental value systems
- Equilibrium
- Sustainability
- Biodiversity
- Strategy.

The issues covered by the course, such as resource management, conservation, pollution, globalization and energy security, are all linked to these key concepts. These concepts can be seen as 'lenses' through which the environmental issues can be viewed, helping you to make cross-connections between different elements of the ESS syllabus.

The **systems** approach is a further concept that is central to the course (see pages 5–6): it helps you to understand complex and dynamic environmental issues, allows you to make connections with other subjects, and enables you to integrate new ideas into what you know already.

Key definitions

System – a set of interrelated parts and the relationships between them, which together constitute an entity or whole.

Environmental value system (EVS) – a particular worldview that shapes the way an individual or group of people perceives and evaluates environmental issues, influenced by cultural, religious, economic and sociopolitical contexts.

Environmental value systems

An **environmental value system (EVS)** 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. There is a range of different EVSs, from ecocentric (a nature-centred EVS) to technocentric (a technology-centred EVS). EVSs determine how individuals and societies respond to environmental issues. Many different factors determine an EVS (Figure 1.1).

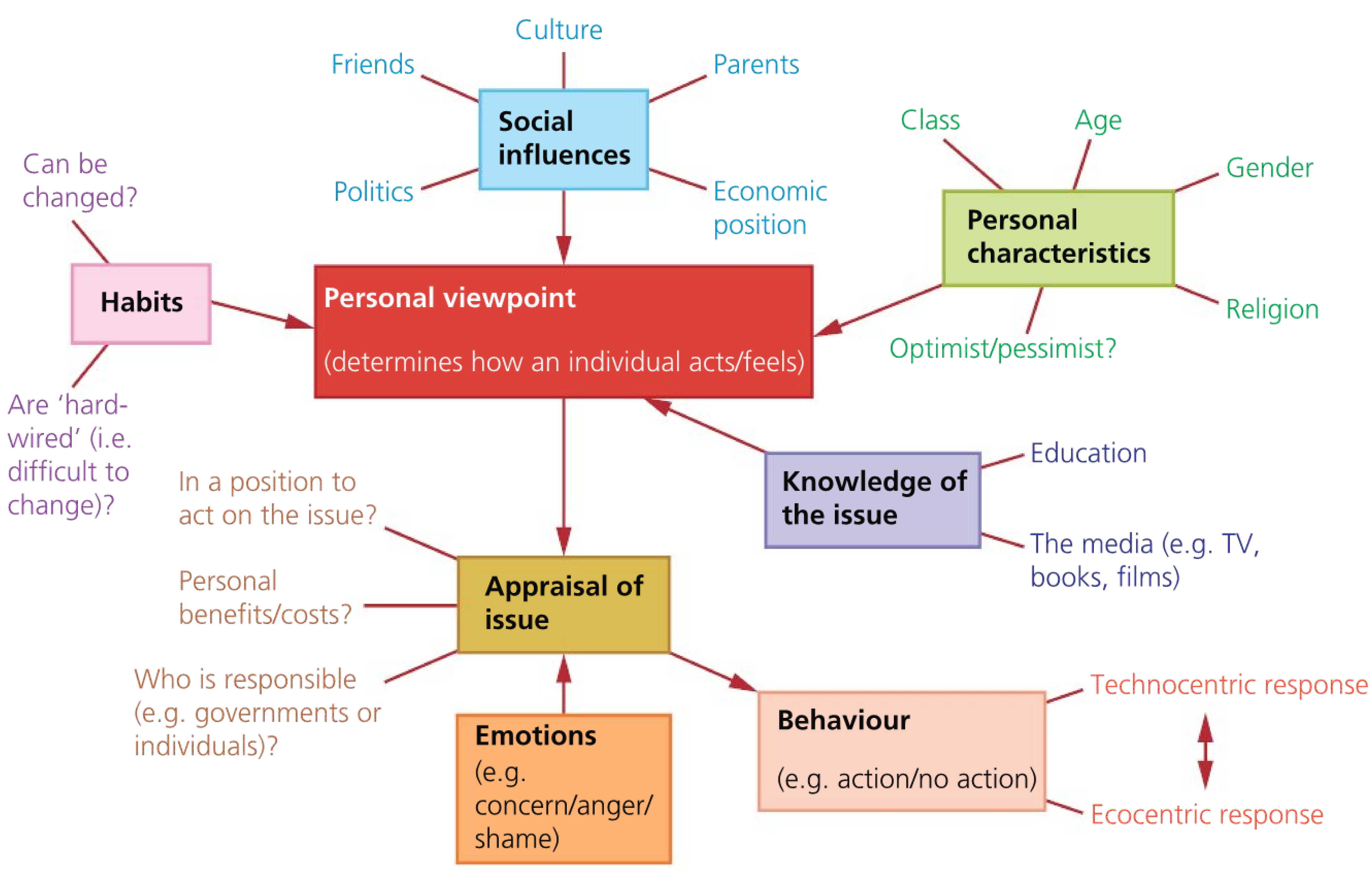


Figure 1.1 Factors that determine an environmental value system

Equilibrium

The concept of **equilibrium** can help us understand the effect of human actions on natural systems. Systems have a tendency to return to the original equilibrium, rather than adopting a new one, following disturbance. **Tipping points** occur when there is a dramatic change in the ecological state, away from equilibrium. They represent points beyond which irreversible change or damage occurs. Such changes are caused by human population growth and associated factors, such as:

- resource consumption
- habitat transformation and fragmentation
- energy production and consumption
- climate change.

Sustainability

Sustainability refers to the use of natural resources in a way that does not reduce or degrade them so that they are available for future generations, and is central to an understanding of the nature of interactions between environmental systems and societies. Resource management issues are essentially ones of sustainability.

Biodiversity

Biodiversity underpins our knowledge of the extent of life on Earth and how it evolved. **Conservation** is closely linked to the concept of biodiversity – to fully appreciate priorities for conservation, the extent of biodiversity needs to be understood.

Strategy

To address environmental issues caused by human actions, clear courses of action are needed. These will be determined by the EVSs of individuals and societies. **Strategy** is the link between evidence and action. For example, when considering the conservation of biodiversity:

- Carefully planned strategies are needed to improve the conservation status of critically endangered species; these strategies need to address the ecological, socio-political or socio-economic pressures that are impacting on the species.
- International conventions provide governments with strategies for conserving biodiversity.
- There are different strategies for conservation: *in situ* conservation preserves biodiversity in natural habitats (for example, protected areas, safari parks), while *ex situ* conservation preserves biodiversity outside natural habitats (for example, zoos).

Throughout the ESS course you will consider strategies to mitigate or adapt to the effects of humanity's impact on the environment.

Key definitions

Equilibrium – a state of balance among the components of a system.

Tipping point – a critical threshold when even a small change can have dramatic effects and cause a disproportionately large response in the overall system.

Sustainability – the use of global resources at a rate that allows natural regeneration and minimizes damage to the environment.

Biodiversity – the amount of biological or living diversity per unit area. It includes the concepts of species diversity, habitat diversity and genetic diversity.

Conservation – the protection of species and ecosystems.

Strategy – a plan of action to achieve specific goals.

System diagrams

The environmental issues you study in ESS are, by their very nature, complex. The subject also links to many disciplines, such as ecology, chemistry, physics, geology, geography, politics and economics. To fully understand the subject, an integrative overview of the issues is needed, linking together many different individual areas of inquiry. The 'systems approach' can be used effectively to make such studies possible and help in the study of complex environmental issues. A system contains components, interlinked through processes and interactions, all of which work together to constitute a whole entity. This holistic approach allows us to appreciate that environmental systems do not function in isolation, but interact with other systems. This is in contrast to a 'reductionist approach', shown by some areas of traditional science, which tends to overlook interactions between systems, meaning that a holistic overview is difficult to achieve. For example, to understand the functioning of a human, many different systems need to be understood, from the cellular through to tissues, organs and organ systems.

Each system has its own **flows** and **storages** of matter, energy or information. Flows are **inputs** and **outputs** to the system and movement within it, for example, energy entering an ecosystem as sunlight, moving along food chains, and being ultimately released from organisms as heat. Storages are the reservoirs of matter, energy or information, for example, the trees within a forest ecosystem that store chemical energy as cellulose and starch, and DNA which stores genetic information in all organisms.

Systems can be shown as diagrams consisting of storages and flows (Figure 1.2). System diagrams are drawn using well-established conventions which apply across all disciplines:

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

Figure 1.2 shows a simple system diagram to describe oceans.

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, harvesting of forest products from plant biomass (Figure 1.3).
- **Transformations** lead to the formation of new products (for example, photosynthesis, which converts carbon dioxide and water, in the presence of solar energy, into glucose and oxygen) or involve a change in state (for example, water evaporating from a leaf into the atmosphere by transpiration – Figure 1.3).

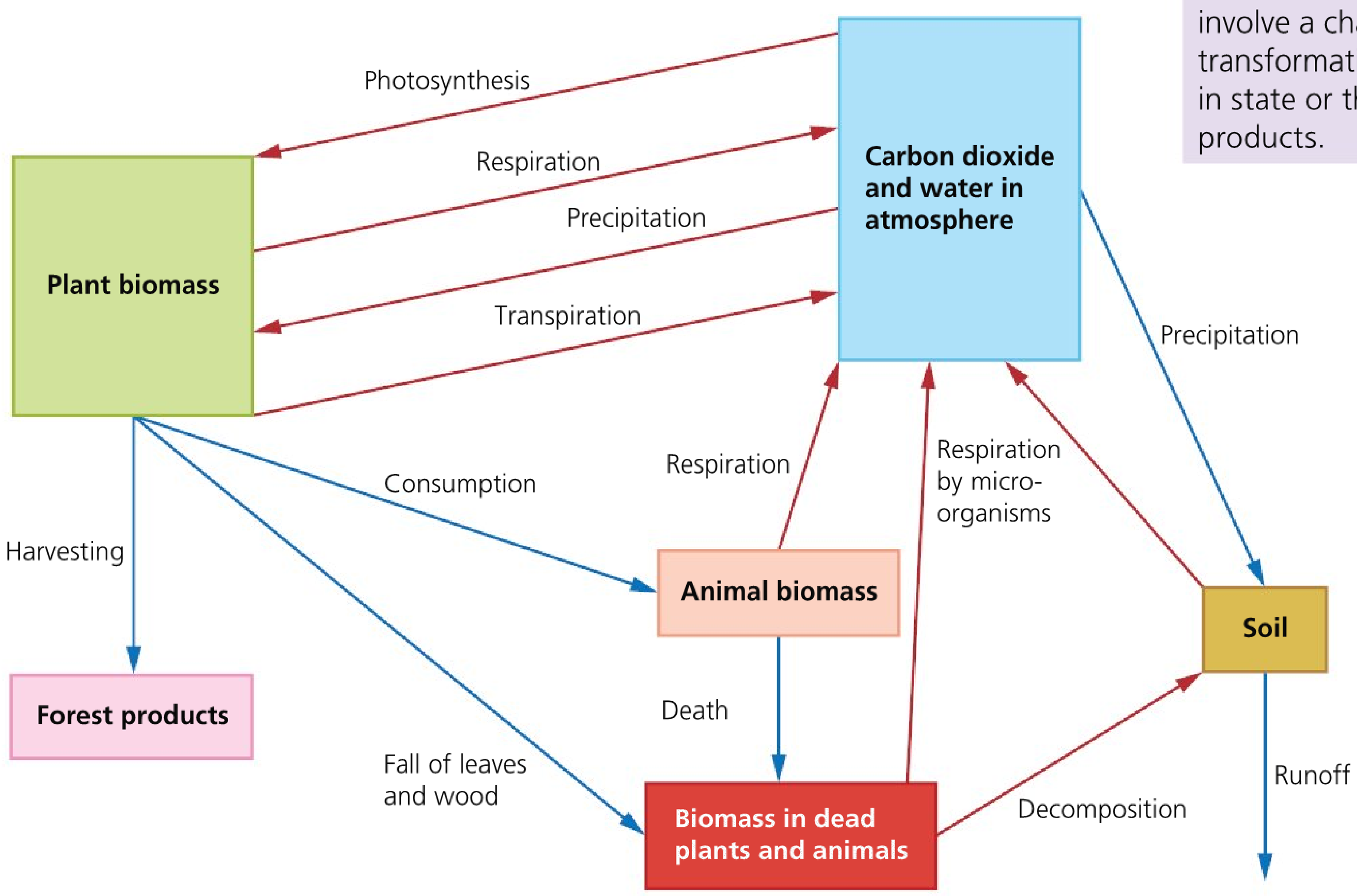


Figure 1.3 Transfers and transformations in an ecological system. Blue arrows represent transfers and red arrows represent transformation processes

Key definitions

Flow – a movement of matter, energy or information between storages in a system.

Storage – the locations where matter, energy or information is held in a system.

Input – a flow entering a storage.

Output – a flow leaving a storage.

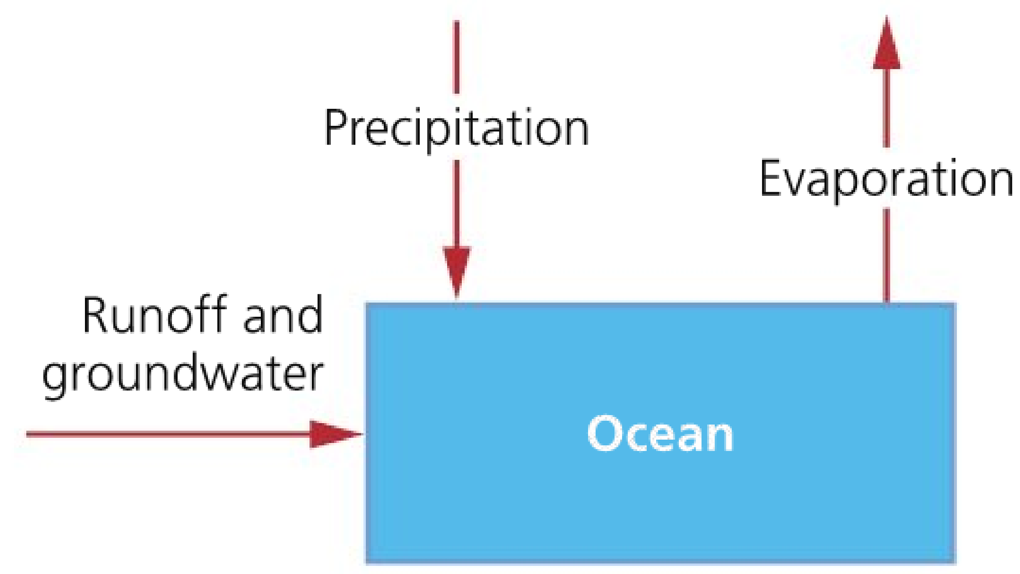


Figure 1.2 A diagram of an ocean system, with flows into and out from the storage (the ocean)

Common mistake

If you are asked in an exam 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. Draw bold, clear, well-labelled diagrams.

Common mistake

Do not confuse transfers with transformations. Transfers only involve a change in location, whereas transformations involve a change in state or the formation of new products.

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

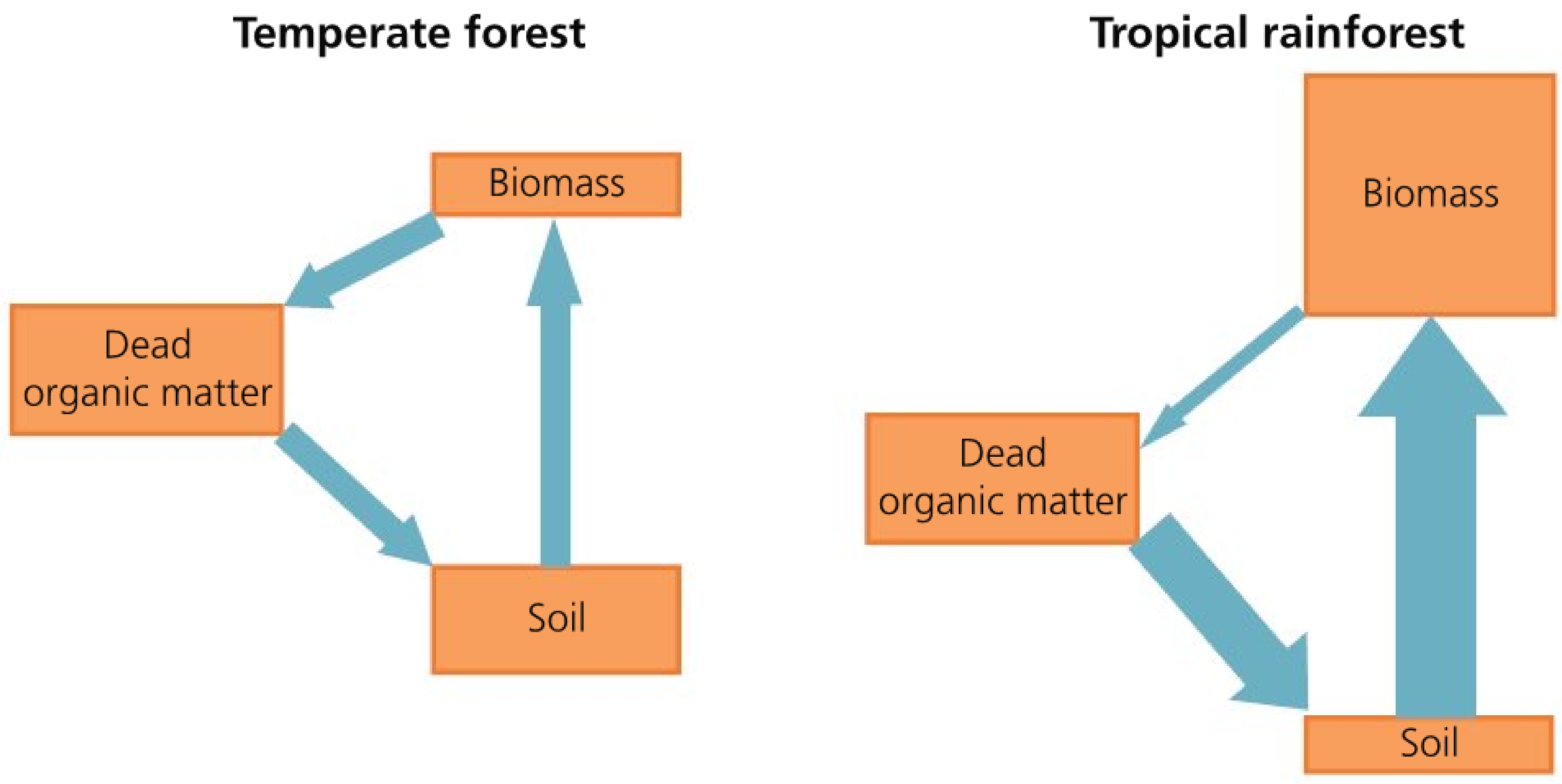


Figure 1.4 Diagrams showing the major nutrient flows and storages in two different ecosystems. The size of the boxes and width of the arrows are proportional to the size of the storages and flows they represent

Using system diagrams to show the effects of human activity

Figure 1.3 shows storages and flows within an ecosystem. It also shows how timber is removed from the forest system. From this, the impacts on the rest of the system can be deduced (for example, reduced plant biomass will lead to reduced photosynthesis and increased carbon dioxide concentration in the atmosphere). System diagrams can be used in this way to show the impact of human activities on the environment, such as the effect of pollution. Figure 1.5, for example, shows how increased combustion of fossil fuels has led to increased warming of the Earth (the **enhanced greenhouse effect**).

Expert tip

When drawing a diagram, include processes on the input and output arrows to show the transfers (blue arrows in Figure 1.3) and transformations (red arrows in Figure 1.3) taking place.

If you have data which indicates the size of the flows or storages, you are expected to show these on diagrams either by drawing boxes and arrows proportionally (Figure 1.4), or by including numbers.

Key definitions

Greenhouse effect – The natural process by which greenhouse gases, especially carbon dioxide, methane and water vapour, allow short-wave radiation to pass through the atmosphere, but trap a proportion of out-going long-wave radiation, thereby warming the Earth's atmosphere.

Enhanced greenhouse effect – increased warming of the Earth due to accelerated emissions of greenhouse gases due to human activities.

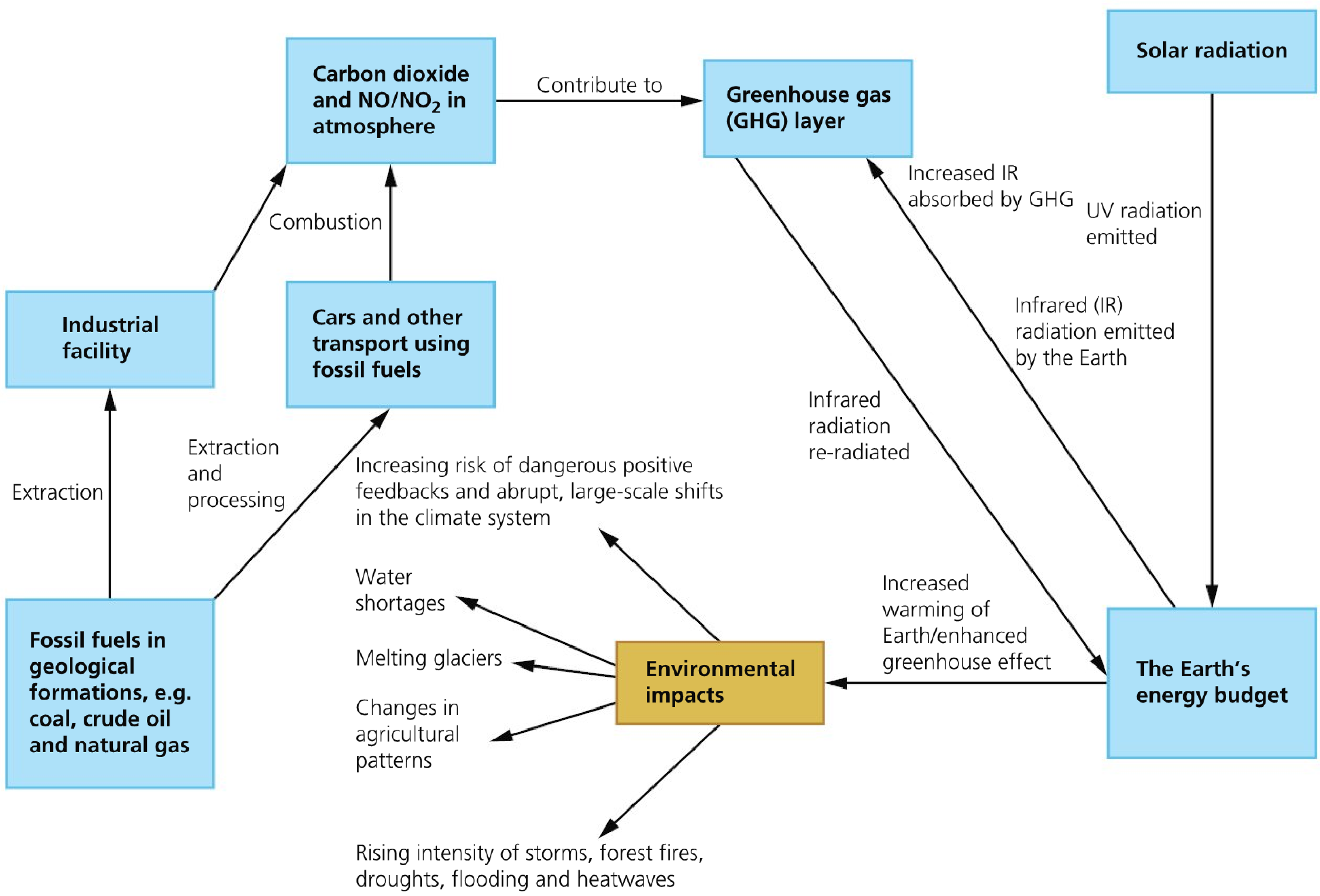


Figure 1.5 System diagram showing the causes and effects of climate change

Ideas for investigations

For any environmental system you are studying, be prepared to draw a system diagram that shows the effects of changed inputs (including human impacts) on the rest of the system, including its outputs.

A system diagram would be a good way of summarizing the results of your IA and indicating possible solutions to the environmental issue you have studied.

ACTIVITIES

1. Construct a system diagram to show the causes and effects of acid rain.
2. List the transfers and transformation processes in the carbon cycle.

Models

A **model** is a simplified version of reality which is used to improve our understanding of how systems work and can help predict how they will respond to change. Computer models use current and past data to generate future **predictions**. All models have strengths and limitations, and inevitably involve some simplification and loss of accuracy. Some models are complex, such as the computer models that predict the effect of climate change. Diagrammatic models (such as the water, carbon and nitrogen cycles) can help visualize the flows, stores and linkages that make up complex systems. System diagrams (see pages 5–6) can be considered models, as they show simplified versions of reality that can be used to indicate interactions and interrelationships within a system.

There are many advantages of using models. They help scientists make predictions about what will happen if there are changes to system inputs, outputs, or storages. Moreover, models allow inputs to be changed and outcomes examined without having to wait a long time (as we would have to if studying real events). In addition, they allow results to be shown to other scientists and to the public and can be easier to understand than detailed information about the whole system.

However, models have limitations too. For example, environmental factors can be very complex with many interrelated components; it may be therefore impossible to take all variables fully into account. Unfortunately, if models are used to provide a simplified representation of reality then they may become less accurate as predictive tools. For example, there are a great many complex factors involved in the operation of atmospheric systems and flows within the carbon cycle. As a result, some climate change sceptics have criticized the models used by the Intergovernmental Panel on Climate Change (IPCC) on the grounds of validity (their argument being that the processes and issues are so complex that any attempt at modelling is likely to result in potentially oversimplified and therefore flawed findings).

Different models may show varying effects and outcomes despite using the same input data. For example, competing models used to predict the effect of climate change can provide contrasting results, and the levels of uncertainty tend to increase the further into the future we look. Moreover, any model is only as good as the data inputs used, and some information may not be reliable in the first place. For example, estimates of the total number of species on Earth are based on mathematical models and vary considerably; issues with identification and classification combined with a lack of finance for scientific research result in many habitats and groups being significantly under-recorded, resulting in unreliable models. Models also rely on the expertise and impartiality of the people making them. Different people may interpret models in varying ways, and so come to different conclusions. People who would gain from the results of particular models or predictions may exhibit bias by using them to their own advantage.

Key definitions

Model – a simplified version of a system. It shows the flows and storages as well as the structure and workings.

Prediction – the expected change in the dependent variable due to a causal change in the independent variable.

Expert tip

The need for models to summarize complex systems requires approximation techniques to be used; these can lead to loss of information and oversimplification. A model inevitably involves some approximation and therefore loss of accuracy. The advantage of models is that they can clearly illustrate links between parts of the system and give a clear overview of complex interrelationships.

Figure 1.6 shows two different climate change pathways modelled by the IPCC. In each case, a range of temperature rises is shown, with differing implications for life on Earth. The global mean surface temperature (GMST) rise prediction for a high emissions scenario varies from 3 °C to 5 °C. This partly reflects the uncertainty around the strength and timing of possible positive feedback loops linked with Arctic permafrost thawing.

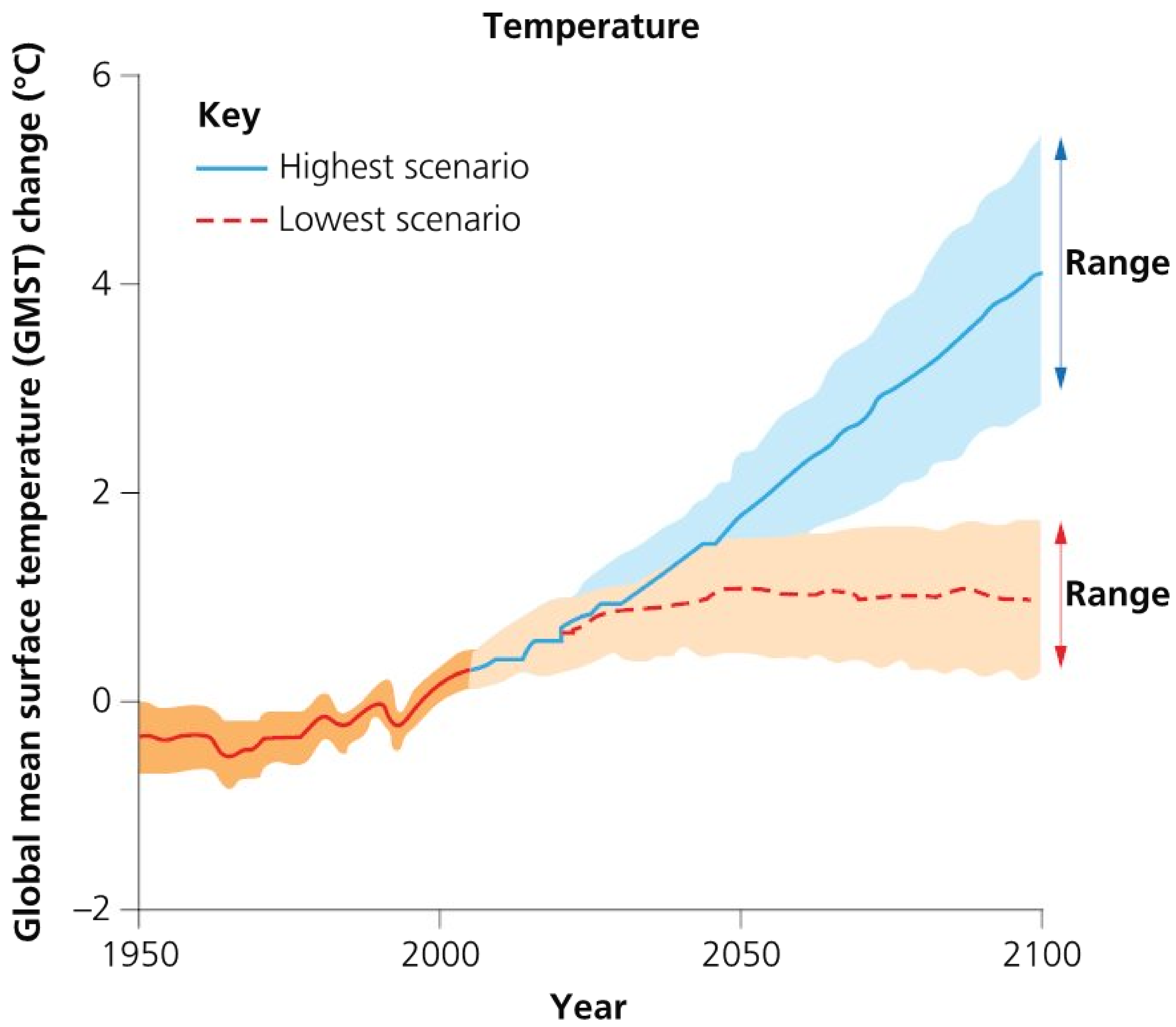


Figure 1.6 Two future pathways modelled by the IPCC

Examples of models you will meet in ESS:

- biogeochemical cycles, such as the carbon, water and nitrogen cycles (other cycles include sulphur and phosphorus – not currently studied in the ESS syllabus)
- feeding relationships in ecosystems, modelled as, for example, food chains, food webs and ecological pyramids
- energy transformations along food chains, used to model the first and second laws of thermodynamics (the principle of conservation of energy and the inefficiency of energy transfer, respectively) – see Figure 1.7 below
- soil profile diagrams to represent the soil system – see Figure 1.8 on the next page
- global climate models – see Figure 1.6 above
- age–gender pyramids and demographic transition models (DTM)
- ecological footprints
- ecosystem modelling (mesocosms or bottle experiments)
- models of sustainability such as maximum sustainable yield.

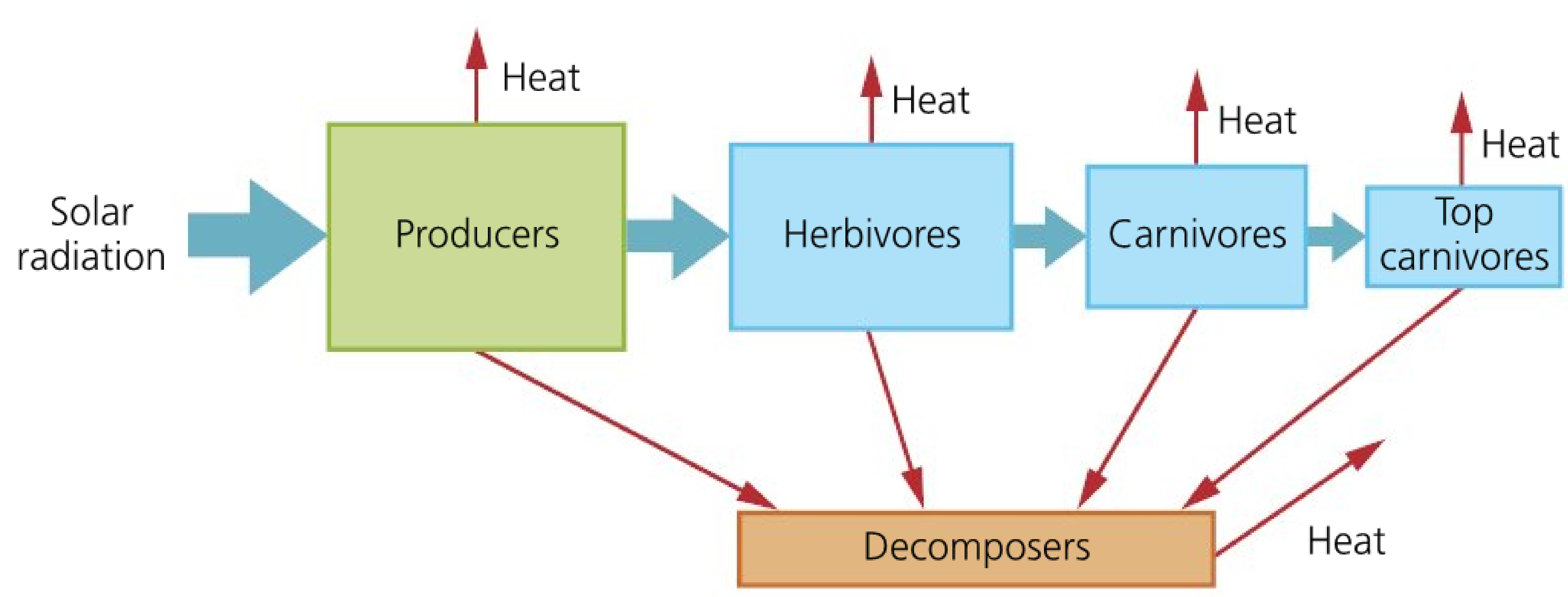


Figure 1.7 Model showing the transfers and transformations of energy as it flows through an ecosystem. Arrows showing flows of energy vary in width, proportional to the amount of energy being transferred

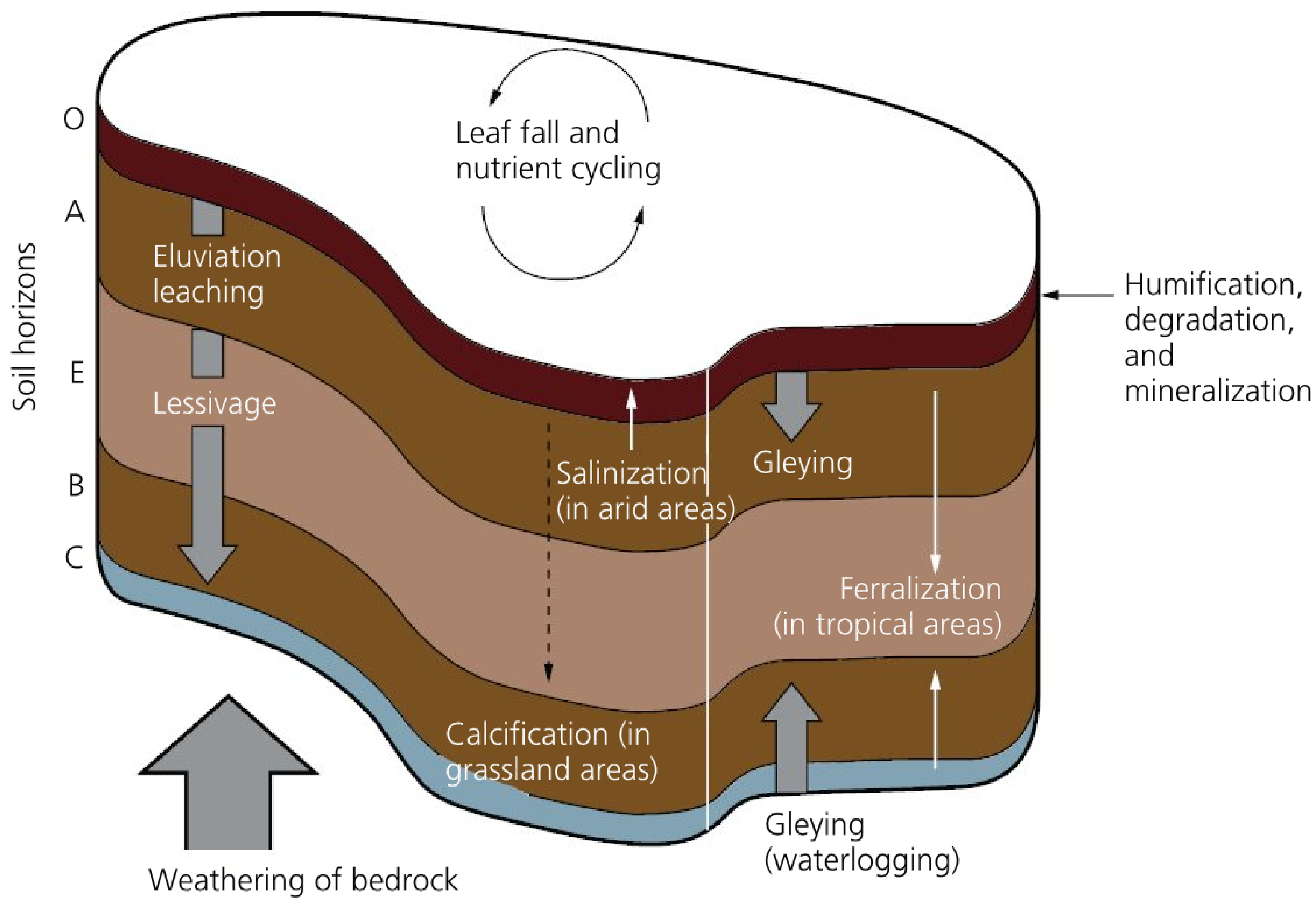


Figure 1.8 A soil profile diagram modelling transfers and transformations in soil. The soil profile shows distinct soil horizons – these include O (organic horizon), A (mixed mineral/organic horizon), E (eluvial or leached horizon), B (illuvial or deposited horizon) and C (bedrock or parent material). Transfers of material (including deposition) result in reorganization of the soil. Transformations include decomposition, weathering and nutrient cycling

Mathematical skills

SI units

An international agreement was reached in 1960 that specified units for use in scientific measurements. These units are called SI units (after the French *Système International d'Unités*). The system is used worldwide to improve communication and to ensure that standard methods are employed. Measurements in the sciences are usually recorded using SI units. The SI system has specified base units from which all other units are derived. These base units, such as kilogram (for mass) and metre (for length), can be modified using prefixes, such as kilo- and milli- (see below), to divide or multiply the base units by factors of ten.

The main SI units used in biological sciences (quantity, unit, and SI unit symbol) are:

- **length** – metre (m)
- **mass** – kilogram (kg)
- **time** – second (s)
- **temperature** – degrees Celsius (°C)*
- **force** – newton (N)
- **pressure** – pascal (Pa)
- **energy** – joule (J)
- **volume** – litre (l)
- **amount of a substance** – mole (mol).

The kelvin (K) is the correct SI unit for temperature, but is rarely used in biology and environmental science, where degrees Celsius is more common.

Volume should, strictly speaking, be measured in cubic metres, m^3, not litres (1 l ≈ 1 dm), however, the litre is more useful in biological sciences and so is widely used.

Expert tip

Here are some general rules when applying SI units:

- Units are always spelt beginning with a lowercase letter, for example, metre. This is also the case when they are named after a scientist, for example, joule.
- Units are always expressed in the singular not the plural, for example, 2 min not 2 mins. (*Note:* This is the case when using the unit symbol, but not when reading the quantity out loud, for example, 5 kg is correct but this is read as 5 kilograms).
- There should be a space between the value and its symbol, for example, 5.00 kg not 5.00kg.
- Use the negative exponent ( ) when expressing units rather than using a forward slash, for example, $m\,s^{-1}$ not m/s.

Expert tip

Examinations usually use the unit cm^3 rather than the unit ml.

Derived SI units

The SI base units can be used to derive the units of other quantities. In each case, an equation is used to define the derived quantity, substituting the appropriate base units. For example, speed is calculated by dividing distance by time, and so the SI unit for speed is the SI unit for distance (metres) divided by the SI unit for time, that is, $m\,s^{-1}$ (metres per second). Other units of measurements include:

- **concentration** – $g\,l^{-1}$ (or $mol\,l^{-1}$/$mol\,dm^{-3}$); for a very low concentration of a solution, 'parts per million' is used (ppm), where one gram in 1000 ml is 1000 ppm and one thousandth of a gram (0.001 g) in 1000 ml is 1 ppm
- **rate of reaction** – $mol\,l^{-1}\,s^{-1}$, that is, change in concentration/change in time (or any other measure of progress/any unit of time). If gases are involved, cm s^{-1} or $dm^3\,s^{-1}$ may be used. If $g\,min^{-1}$ are measured (that is, change in mass over time) this is not strictly speaking the rate of reaction, but is **proportional** to the rate of reaction
- **energy flux** – $J\,m^{-2}\,s^{-1}$
- **mass flow** – $kg\,s^{-1}$
- **surface tension** – $N\,m^{-1}$
- **frequency** – temporal frequency (for example, s^{-1}) and spatial frequency (for example, m^{-1})
- **productivity** – mass or energy per unit area (or volume) per unit time, that is, $m^{-2}\,y^{-1}$ or $J\,m^{-2}\,y^{-1}$. Productivity is the rate of generation of biomass in an ecosystem (see Chapter 2, page 36). Because it is measured over long periods of time, a non-SI unit, year, is generally used for time.

Some measurements, such as logarithmic functions and absorbances, have no units. The pH scale, for example, is logarithmic. A logarithmic scale compresses the range of values, and gives more space to smaller values while compressing the range available for the larger values. Each cycle on the scale increases by a power of 10: for example, in the first cycle, values would be 1, 2, 3, 4, etc., whereas in the second cycle they would be 10, 20, 30, 40, and so on, and in the third cycle 100, 200, 300, 400, etc. See Chapter 14, page 161, for further information about logarithmic scales and how they are plotted.

Expert tip

Quantities that represent ratios of two values, such as absorbance, do not have units. Both pH and absorbance are unit-less since they are logarithmic functions (pH = $-\log_{10}[H^+(aq)]$; absorbance = $\log_{10}(I_o/I)$), and logarithms are always pure numbers which have no units.

Photosynthetic efficiency (and other measures of ecological efficiency) also does not have units. This is calculated by dividing the incident radiation (converted to NPP – see page 36) by total incident radiation and multiplying this number by 100, that is:

$$\frac{\text{incident radiation converted to NPP}}{\text{total incident radiation}} \quad 100$$

Examiner guidance

For logarithms, retain in the mantissa (the number to the right of the decimal point in the logarithm) the same number of significant figures as there are in the number whose logarithm you are taking. For example: log(12.8) = 1.107. The mantissa is .107 and has 3 significant figures because 12.8 has 3 significant figures.

Common mistake

When referring to units of temperature, never use the term 'centigrade'. The correct unit of measurement is degrees Celsius.

Examiner guidance

Imperial units such as feet, pounds and inches are still used routinely in agriculture and forestry in the United States. They should be converted to SI units.

Expert tip

For some ecology investigations, units of temporal frequency (for example, s) or spatial frequency (for example, m) are more appropriate than units of time or distance.

Expert tip

Absorbance is a logarithmic function and so does not have a unit.

Expert tip

The fact that pH is logarithmic (to the base 10) means that pH 6.0 is 10 times more acidic than pH 7.0; natural rainwater at pH 5.5 is approximately 30 times more acidic than distilled water at pH 7.0. Acid rain is frequently more than 20 times more acidic than natural rainwater.

Non-SI units

Some measurements do not use SI units. Some of these have already been explored (such as volume measurement in litres and temperature measurement in degrees Celsius). Other non-SI units are shown in Table 1.1.

Quantity	Non-SI unit	Unit symbol	Conversion factor/use
energy	calorie	cal	1 cal = 4.184 J
mass	tonne	t	1 t = 10 kg
area	hectare	ha	1 ha = 100 m × 100 m (that is, 10 000 m^2)
light intensity	lux	lx	1 lx = 1 lm m^{-2} (lumen per square metre)
cells per sample	colony forming unit	cfu	estimating the number of viable bacteria or fungal cells in a sample
time	minute	min	1 min = 60 s
	hour	h	1 h = 3600 s
	day	d	1 d = 86 400 s
	year	yr	1 yr = *ca.* 31 557 600 s (31.6 ms)
pressure	millibar	mbar or mb	1 mbar = 100 Pa
	millimetre of mercury	mmHg	1 mmHg = 133.322 Pa
speed	knot	kn	1 kn = one nautical mile per hour = 1.852 kmh^{-1}

Table 1.1 Non-SI units

Expert tip

SI units should be used for recording all units except where non-SI units are in common usage. Examples of non-SI units that may be more appropriate (depending on context) in many ecological and forestry measurements are ha rather than m^2 and year rather than second. Tree diameter will generally be recorded in cm rather than m.

The energy content of dried foods, biomass or fuels is usually expressed in either kilojoules or kilocalories per unit mass or per unit volume. A calorie (cal) is the amount of heat energy required to heat one gram of water through one degree Celsius. 1 calorie = 4.184 J. A kilocalorie (kcal or Cal) is a unit of energy of one thousand calories.

Scientific notation

Numbers in science are often extremely large or extremely small. Consider the mass of a tobacco mosaic virus and the mass of the Sun, for example. They can be written as: 0.000000000000000000000000068 kilograms and 1 989 100 000 000 000 000 000 000 000 000 kilograms, respectively.

However, this notation uses many zeros and so there is a possibility of making a mistake when writing a value. Scientific notation is a way of expressing large and small numbers while avoiding lots of zeros. It uses the form:

$N \times 10$

where N is a number between 1 and 10 and n is the exponent or the power to which 10 is raised. So in scientific notation, the mass of a tobacco mosaic virus can be written as 6.8×10^{-26} kg and the mass of the Sun as 1.9891×10^{30} kg.

As the definition implies and the following examples show, any number – not just large or small numbers – can be expressed in scientific notation:

$97\,400 = 9.74 \times 10$

$106.8 = 1.068 \times 10^2$

$10 = 1 \times 10^1$

$0.0029 = 2.9 \times 10^{-3}$

$0.005810 = 5.810 \times 10^{-3}$

Scientific notation is not merely a more convenient way of expressing numbers, it makes it easier to track significant figures.

Expert tip

Prefixes increase or decrease by factors of a thousand. This is known as the 'thousands rule'. By choosing the correct prefix, all values will be in the range 1–999. For example, 20 mm should be used instead of 0.02 m, and 3.72 MPa instead of 3 720 000 Pa.

Standard prefixes can be used to record large or very small numbers:

For large numbers:

10^3 = kilo (k) – for example, kilometre (km)

10^6 = mega (M) – for example, megametre (Mm)

10^9 = giga (G) – for example, gigametre (Gm)

10^{12} = tera (T) – for example, teragram (Tg)

For small numbers:

10^{-3} = milli (m) – for example, millilitre (ml)

10^{-6} = micro (μ) – for example, micrometre (μm)

10^{-9} = nano (n) – for example, nanometre (nm)

10^{-12} = pico (p) – for example, picometre (pm)

Figure 1.9 shows the importance of prefixes when referring to different levels of scale.

Common mistake

When recording units of time, never use 'sec' – the correct unit for seconds is 's'.

Common mistake

The prefixes 'deci' (d, 10^{-1}) and 'centi' (c, 10^{-2}), for example, dm (decimetre) and cm (centimetre), do not follow the 'thousands rule' (see Expert tip box on page 12) and so cause confusion. They should be avoided.

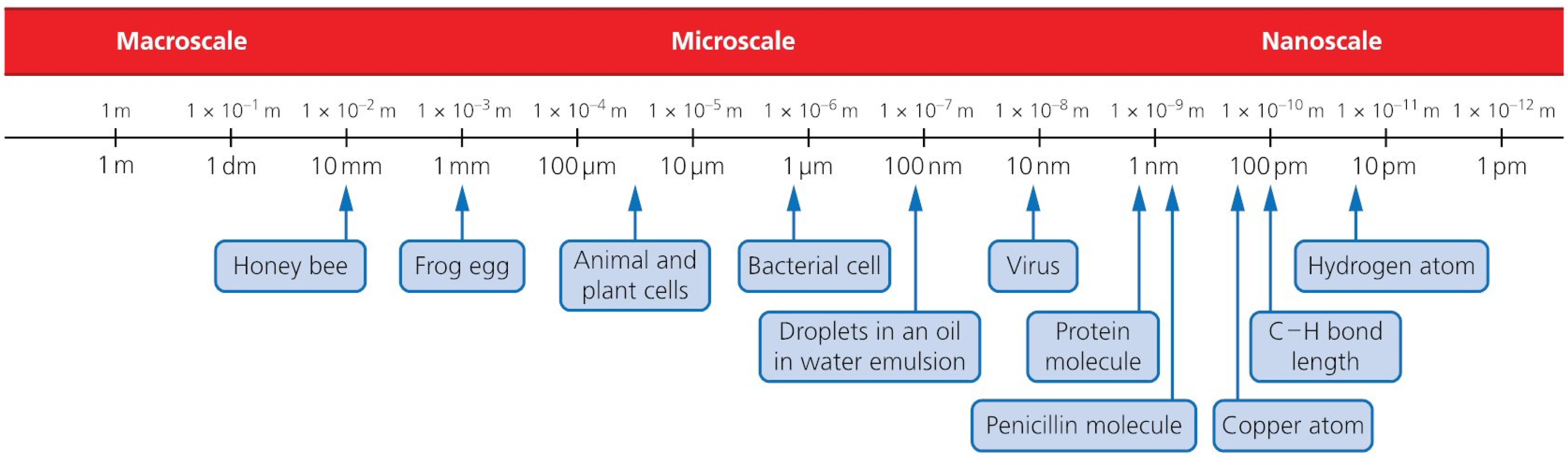


Figure 1.9 Units of distance from large scale (macroscale) to very small scale (nanoscale)

ACTIVITIES

3 Write the following numbers in scientific notation:
1002, 54, 6 926 300 000, –393, 0.00361 and –0.0038.

4 Write the following numbers in ordinary notation:
1.93×10^3, 3.052×10^1, -4.29×10^2, 6.261×10^6 and 9.513×10^{-8}.

5 What is the name given to the unit that equals
- **a** 10^{-9} gram
- **b** 10^{-6} second
- **c** 10^{-3} metre?

6
- **a** What decimal fraction of a second is a picosecond (ps)?
- **b** Express the measurement 4.0×10^3 m using a prefix to replace the power of ten.
- **c** Use standard exponential notation to express 4.56 mg in grams.

Expert tip

Where appropriate, units for time can include seconds (s), minutes (min), hours (h), days (d) and years (y). For example, in ecological investigations, longer timescales might be more appropriate than seconds. Do not record data using a mixture of units, such as minutes and seconds, for example, 5 min 2 s.

Concept of significant figures

The number of significant figures (sf) in a numerical result is an indication of the accepted error in a measurement. The result of a calculation that involves measured values cannot be more certain than the least certain of the data that are used. Therefore, the result should contain the same number of significant figures as the measurement that has the smallest number of significant figures.

The following rules should be applied to establish the number of sf in a number:

- Zeros between digits are significant. For example, 2006 g has four significant figures.
- Zeros to the left of the first non-zero digit are not significant (even when there is a decimal point in the number). For example, 0.005 g has one significant figure.

- When a number with a decimal point ends in zeros to the right of the decimal point, these zeros are significant. For example, 2.0050 g has five significant figures.
- When a number with no decimal point ends in several zeros, these zeros may or may not be significant. The number of significant figures should then be stated or the number should be written in scientific notation (standard form). For example, 30 000 g (to 3 sf) means that the mass has been measured to the nearest 100, while 30 000 g (to 4 sf) means that the mass has been measured to the nearest 10.

When significant figures are used as an implicit way of indicating uncertainty, the last digit is considered uncertain. For example, a result reported as 1.23 implies a minimum uncertainty of ±0.01 (or a maximum uncertainty of ±0.05) and a range of 1.22 to 1.24. Figure 1.10 shows the concept of uncertainty, which is explored in more detail later in this book (pages 162–164).

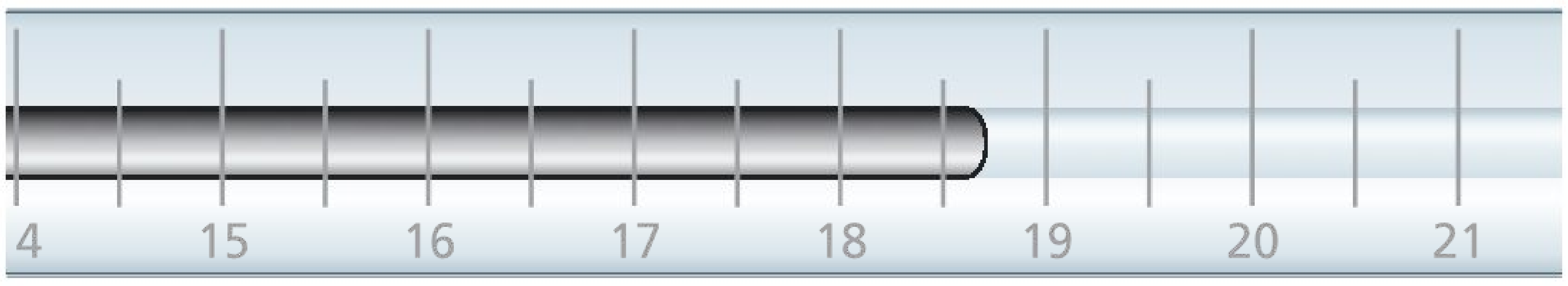


Figure 1.10 A magnified thermometer scale showing a temperature of 18.7 °C: the last digit is uncertain

ACTIVITY

7 State and explain the number of significant figures in the following measurements:

14.44, 9 000, 3 000.0, 1.046, 0.26 and 6.02×10^{23}.

Examiner guidance

For multiple calculations, just follow the order: first logarithms and exponents, then multiplication and division, and finally addition and subtraction. When parentheses are used, do the operations inside the parentheses first.

Rounding off significant figures

Sometimes it is necessary to round off, to give the correct number of significant figures.

- A digit of 5 or larger rounds up.
- A digit smaller than 5 rounds down.

The number 350.99 rounded to:

4 sf is 351.0

3 sf is 351

2 sf is 350

1 sf is 400

Notice that when rounding you only look at the one figure beyond the number of figures to which you are rounding, that is, to round to three significant figures you only look at the fourth figure.

Rounding depends on the number of significant figures allowed by the accuracy of the initial measurements.

Expert tip

Placeholder zeros can be removed by converting numbers to scientific notation. For example, 2 000 may have anywhere from one to four sf, but by writing the number in scientific notation the number of sf is made explicit; for example, by writing the number as 2.00×10 it is made clear that it has 3 sf.

Expert tip

30–300 rule

This rule is used to determine how accurately to measure a variable. The number of significant digits should be such that there are 30 to 300 units (approximately) between the largest and smallest measurement. For example, when measuring sardine lengths that range between 4 and 8 cm, there are only 4 cm between the largest and smallest values. The degree of accuracy that 1 cm intervals provides is not adequate. If the sardines are measured in 0.1 cm between 4.0 and 8.0 cm, there are 40 units of 0.1 cm between the largest and smallest values.

Common mistake

A common mistake is to simply copy down the final answer from the display of a calculator. This often has far more significant figures than the measurements justify and you will lose marks for this under the Analysis and Communication criterion of your IA.

ACTIVITY

8 Report the following numbers to three significant figures:
654.389, 65.4389, 654 389, 56.7688 and 0.03542210.

Measurement: area, volume, mass and temperature

Area

The metre (m) is the SI base unit of length. Area is measured in squared units of length (m^2), and so is a two-dimensional measurement.

Volume

Volume is the space occupied by an object. The volume of a cube is given by its length cubed, that is, length^3, and so is a three-dimensional measurement. This means that the SI base unit of volume is the cubic metre (m^3) – that is, the volume of a cube that is 1 m on each edge. Smaller units, such as cubic centimetres, cm^3, are often used in biology. A litre (l) is equivalent to a cubic decimetre, dm^3. As discussed above, the litre is not a standard SI unit, but is frequently used in biological studies.

- 1000 millilitres (ml) = 1 litre
- Each millilitre is approximately the same volume as a cubic centimetre: 1 ml ≈ 1 cm^3.

Various devices are available to transfer and deliver, or measure, a volume of liquid or solution:

- A pipette can be used to extract and deliver volumes of liquid or solution.
  - They are used to transfer small volumes, typically 25 ml or less.
  - A suction bulb draws fluid into the pipette.
  - The mouth should never be used to suck fluid into a pipette.
  - Markings on a graduated pipette allow precise measurement of the volume of a liquid or solution.
- A graduated cylinder or measuring cylinder can be used to measure volumes.
  - They are used to measure larger volumes, or when the precision of the measurement is less critical.
  - The measurement should always be taken from the bottom of the meniscus (the interface between the water and air – it is curved because of surface tension and the adhesion of water to the sides of the cylinder) – see Figure 1.11. **Parallax error** occurs when there is a displacement or difference in the apparent position of an object viewed along two different lines of sight.
  - Care should be taken to remove as much of the liquid or solution from the measuring cylinder as possible, although there will always be some remaining (a limitation of this technique).
- Burettes can also be used to measure volumes of liquid or solution.
  - They are similar to a graduated cylinder but have a stopcock at the bottom.
  - They can be used to transfer liquids but are mainly used in titrations.
  - The flow of liquid is controlled using the stopcock – it can be left completely open to allow a continuous flow or set to release one drop at a time.

Expert tip

When measuring pure water, the SI system offers an easy and common conversion from volume (litre) to mass (gram): 1 ml ≈ 1 cm^3 ≈ 1 g. 'Approximately equal' (≈) signs are used because the density of water varies with temperature – it has maximum density of 1 $g\,cm^{-3}$ at 4 °C.

Expert tip

The volume of a solid object can be measured by water displacement. Water is put into a beaker, measuring cylinder or other glassware with a graduated measuring scale. The initial volume of water is recorded. The object is submerged in the water – the volume of the contents rises. The level of the meniscus of the water is read and the volume recorded. The volume of the object is calculated by subtracting the original volume from the final volume.

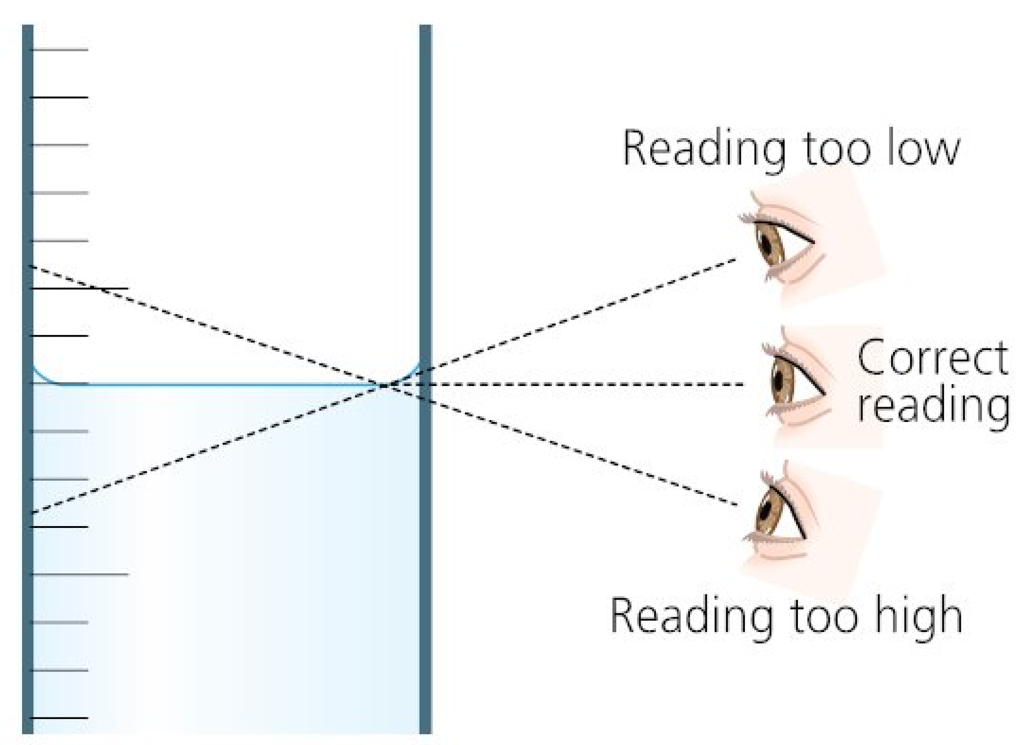


Figure 1.11 Parallax error with a measuring cylinder

Expert tip

When measuring the liquid in a graduated measuring cylinder, the meniscus should be read with eyes level with the meniscus. Read the volume at the lowest level.

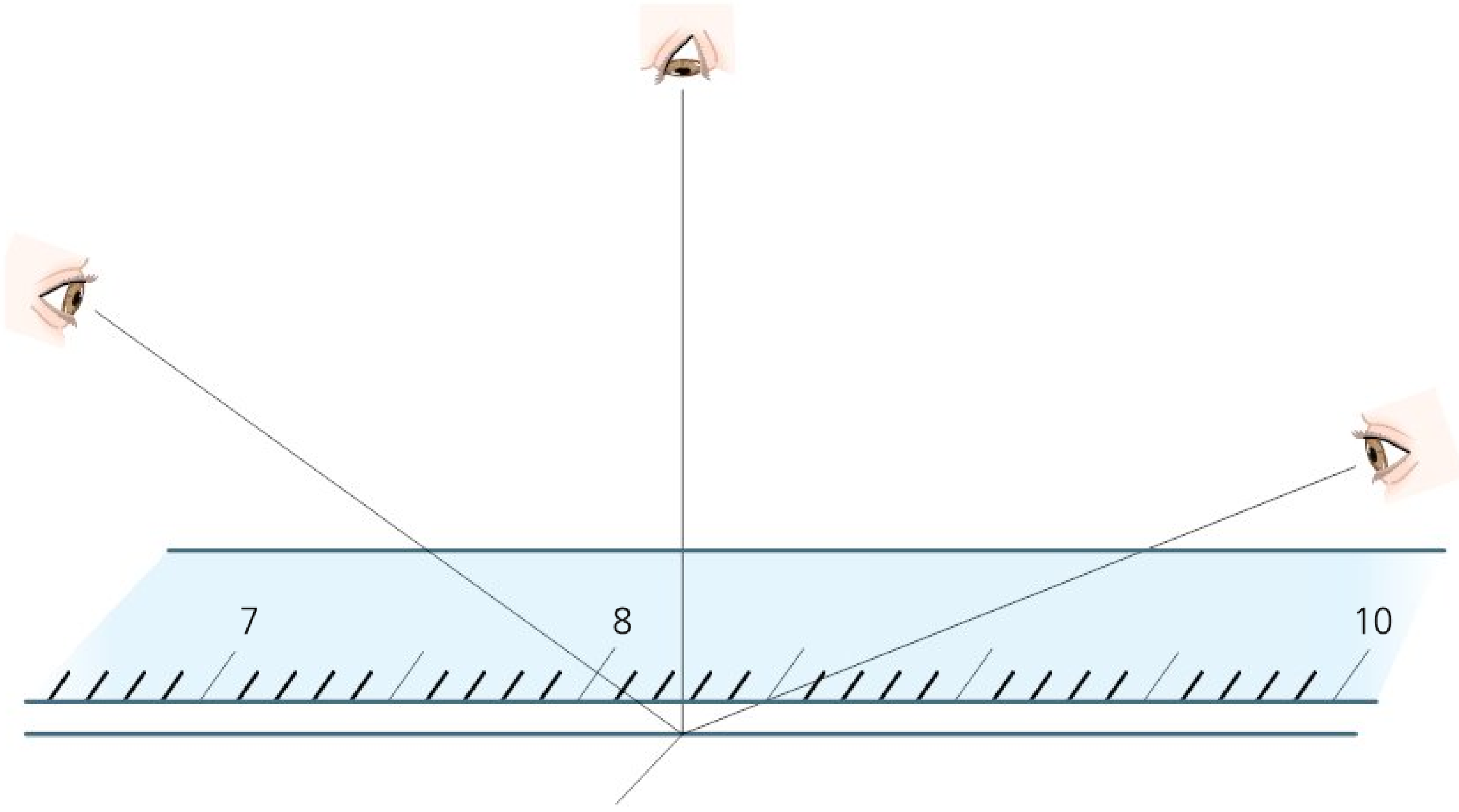


Figure 1.12 Parallax error when reading a metre ruler

> **Expert tip**
>
> As well as measuring volumes, parallax error must also be considered when using a ruler (see Figure 1.12).

Mass

The kilogram (kg) is the SI base unit of mass. Electronic balances are usually used to record the mass of an object.

- Before making any measurements, clean the weighing pan gently with a soft brush.
- Zero the balance, so it indicates '0 g' (zero grams).
- Measure the mass of an object by placing it in the centre of the weighing pan.
- Take care to ensure the balance is zeroed between each measurement.
- Hot samples should be cooled to room temperature because heat creates convection currents that cause the mass displayed to be unreliable.
- Some balances have doors that need to be shut, to ensure air movement does not affect measurements.
- Use an analytical balance to record the mass of live animal specimens – these balances often have a draft shield to prevent air currents from interfering with the measurement.

Temperature

Temperature is a measure of the average kinetic energy of molecules in a system. In your practicals you will likely measure temperature using a thermometer calibrated in degrees Celsius (°C). The Celsius scale is based on water freezing at 0 °C and boiling at 100 °C at 1 atm pressure. Digital thermometers are the most accurate, and safest, way of recording temperature (Figure 1.13).

Figure 1.13 A digital thermometer being used to record soil temperature

> **Expert tip**
>
> 'Heat' and 'temperature' are often used interchangeably, but they are actually different, although closely related, concepts. Temperature is a measure of the average kinetic energy of molecular motion in a substance whereas heat is the total energy of molecular motion in a substance. Temperature is measured in degrees Celsius; heat is measured in joules.

> **Expert tip**
>
> Degrees Celsius (°C) and degrees Fahrenheit (°F) can be interconverted using the formula
>
> $$°F = \frac{9}{5}°C + 32$$
>
> (*Note:* for your IA report you should use °C because °F is not an SI unit.)

Data collection

Sketch maps and diagrams

A sketch map is a summary of the main features of a more detailed map, or it may just be drawn from personal observation from a good vantage point. It may in fact be a combination of both of these elements. Because it is a map there will be reference to both scale and direction.

Personal observations or perceptions may form an important element of a coursework investigation or other types of inquiry. As an ESS student you are expected to be observant. Sketch maps and diagrams are a very good way of recording what you have seen and are a good way to develop observation skills.

Field sketches are a very important primary data collection tool. A field sketch is a hand-drawn summary of an environment you are studying. In both urban and rural environments, field sketching is a very useful way of recording the most important aspects of a landscape and noting the relationships between elements of such landscapes. However, most of the field sketches that appear in books are of physical environments. The action of stopping for a period of time to sketch the landscape in front of you will often reveal details which may not have been apparent from a quicker look.

Figure 1.14 is an example of a good field sketch. With careful and selective annotation, this sketch highlights the important geographical features of the landscape. Key features should be clearly labelled and annotated, but make sure that your sketch map is not too cluttered. This will detract from the really important details. Look for specific, small-scale features and larger more general features. The accurate use of arrows to pinpoint key features is important. A good field sketch will be viewed as a higher-level technique by your ESS coursework moderator.

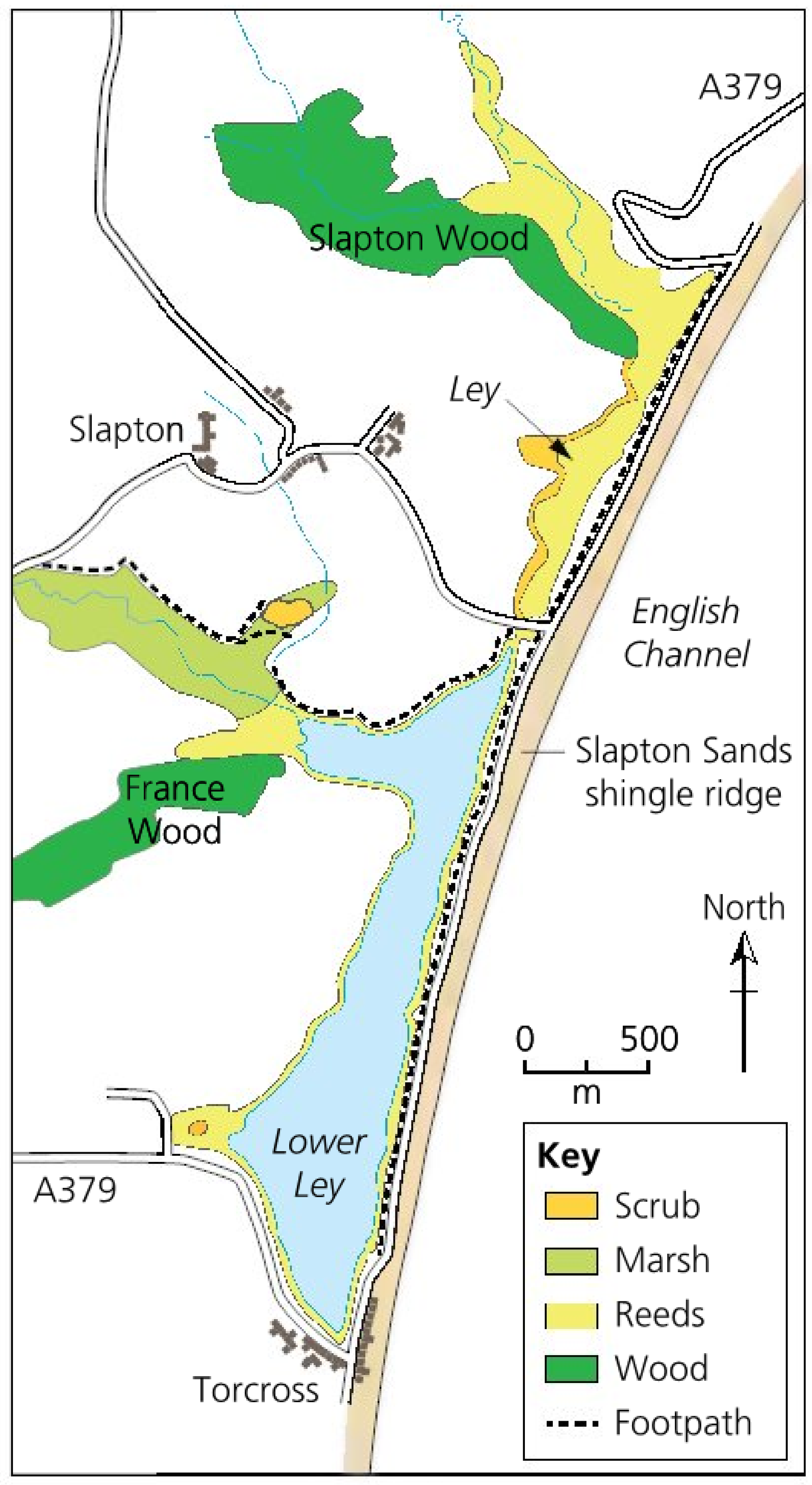


Figure 1.14 Field sketch map of Slapton Ley

You do not need a high level of artistic ability to produce a good field sketch. What is important is that your drawing is clear and that your annotations give good, but brief, description and explanation. However, if you still feel uncomfortable about drawing a field sketch then an annotated photograph is the best alternative (see pages 18–19). The main advantage of a field sketch over a photograph is that in a field sketch you can omit detail that you feel is not relevant to your inquiry. Figure 1.15 summarizes the most important aspects of a good annotated sketch map or diagram.

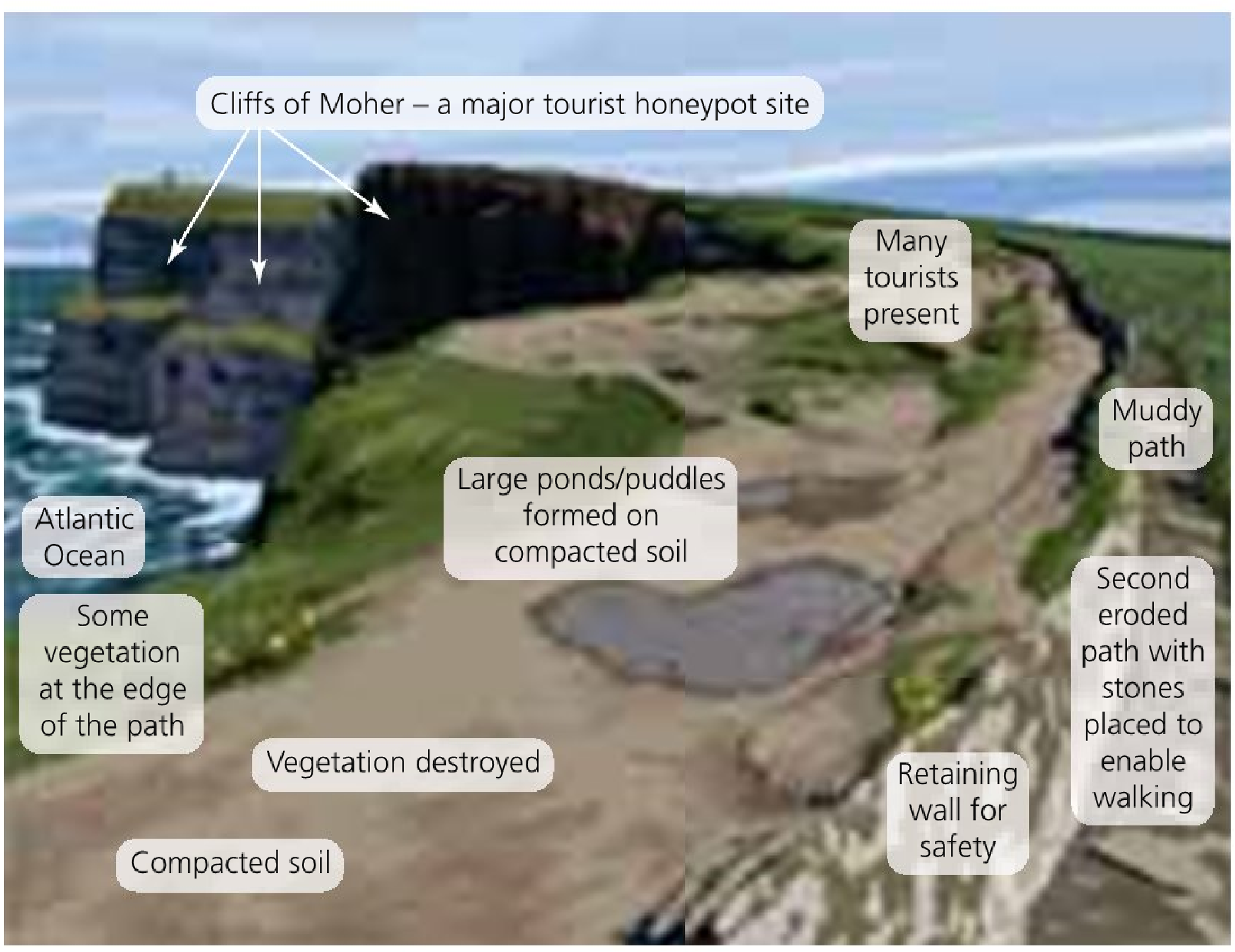


Figure 1.15 An example of a sketch diagram, showing severe soil erosion at the Cliffs of Moher, County Clare, Ireland

Key points

- Use a pencil for your drawing so that you can make changes easily and quickly.
- Show clear boundaries in all directions.
- Ensure that your map or diagram is large enough to show all necessary detail and can comfortably accommodate the annotations you are going to add.
- Include a clear and accurate title which refers to the location of the map or diagram.
- Where appropriate, refer to direction and scale.
- Annotations should be clearly and neatly presented in short, sharp sentences which are mainly descriptive but may also offer some brief explanation.
- For a sketch diagram it might be useful to pinpoint the sketch site on a location map.
- Refer clearly to your map or diagram in the text by giving it a figure number, for example, 'Figure 2 is a sketch map of Lulworth Cove'.

ACTIVITIES

9 What is a field sketch?

10 Find a good example of an annotated sketch map in one of your textbooks or in a book from the library. Explain why your selection is a particularly good example.

Annotated photographs

Annotated photographs should be seen as complementing field sketches rather than being just an alternative to them. Like field sketches, good, fully annotated photographs are regarded as a higher-level skill. Always record the precise location and the conditions of the photographs you take. This should include grid reference, the direction the photograph was taken in, weather conditions and time of day. Such information will make annotation quicker and easier in the long run, as the annotation you complete in the field may be rather brief because of time limitations, and you will want to elaborate on this when you get back to school.

Often photographs are taken when a field sketch is impractical because of a lack of time, or due to other circumstances such as high winds, or when the subject matter is fast-moving or short-lived such as different types of traffic movements. Attempts to capture dramatic events and unusual light conditions favour photographs over the alternatives. Photographs are also clearly preferable when group work is taking place and when field equipment is being used. It would be difficult for most people to capture these images in a field sketch. When trying to present evidence to justify conclusions you have drawn, a photograph may provide the accuracy and detail that cannot be obtained from a field sketch.

An annotated photograph shows your key perceptions about a location you have visited during fieldwork. A series of such photographs might show how:

- the type and quality of housing varies in an inner city or suburban area
- a river and its valley change from source to mouth
- a beach varies in profile from one end to another
- a greenfield site is gradually developed.

As with sketches and diagrams, annotations should be in the form of short, sharp sentences. Moderate abbreviation is fine providing the meaning of the comment remains clear. Some annotations will be just descriptive, but where the opportunity arises some explanation should also be included. Annotation can be most effective when the photograph is placed on the page in landscape format, which will allow more space for annotations on all four sides. As with field sketches, a series of annotated photographs could form a very effective part of your analysis. You should look to correlate annotated photographs with the tables and graphs showing your data analysis. Photographs are also useful to show how you carried out surveys and field measurements. They can show that you really know how to use equipment, such as a flow meter or a clinometer. Figure 1.16 is an example of an annotated photograph of part of an out-of-town retail unit.

Figure 1.16 An example of an annotated photograph

Questionnaires

The **questionnaire** is a very useful technique for investigating patterns, trends and attitudes. It is often used to complement information obtained by other techniques such as observation. Questionnaire surveys involve both setting questions and obtaining answers. The questions are pre-planned and set out on a specially prepared form.

The questionnaire survey is probably the most widely used method to obtain primary data in human geography. In the wider world questionnaires are used for a variety of purposes, including market research by manufacturing and retail companies, and to test public opinion prior to political elections.

Questionnaires may contain:

- closed questions with a fixed choice of answers to generate data for easy analysis
- open questions with space to give answers for more detailed, individual answers
- scale questions.

Key definition

Questionnaire – a document that asks the same questions of all individuals in a sample.

One of the most important decisions is how many questionnaires you are going to issue. The general rules to follow here are similar to those for sampling. Remember, if you have too few questionnaire results, you will not be able to draw reliable conclusions. For most types of study, 25 questionnaires is probably the minimum you would need in order to draw reasonable conclusions. On the other hand, it is unlikely you would have time for more than 100 unless you were collecting data as part of a group.

A good questionnaire:

- has a limited number of questions that take no more than a few minutes to answer
- is clearly set out so that the questioner can move quickly from one question to the next. People do not like to be kept waiting; the careful use of tick boxes can help to meet this objective
- is carefully worded so that the respondents are clear about the meaning of each question
- follows a logical sequence so that respondents can see 'where the questionnaire is going' – if a questionnaire is too complicated and long-winded people may decide to stop halfway through
- avoids questions that are too personal
- begins with the quickest questions to answer and leaves the longer/more difficult questions to the end
- reminds the questioner to thank respondents for their cooperation.

The disadvantages of questionnaires are:

- The response rate may be lower than you anticipate. Many people may not want to cooperate for a variety of reasons. Some people will simply be too busy, others may be uneasy about talking to strangers, while some people may be concerned about the possibility of identity theft.
- Research has indicated that people do not always provide accurate answers in surveys. Some people are tempted to give the answer that they think the questioner wants to hear or the answer they think reflects well on them.
- Questionnaires are not suitable for investigating long, complex issues.

As with other forms of data collection, it is advisable to carry out a brief pilot survey first. It could be that some words or questions you find easy to understand cause problems for some people. Amending the questionnaire in the light of the pilot survey before you begin the survey proper will make everything go much more smoothly. The Worked example on pages 21–22 shows the difference between a good, carefully constructed questionnaire and a much less effective one that was prepared quickly.

Expert tip

Do not work on your own even if you are working on an individual ESS project; work in small groups when carrying out questionnaires or interviews, or at least have one of your classmates visible. Always carry a mobile phone.

Delivering the questionnaire

There are three options:

- Approach people in the street or in another public place.
- Knock on people's doors.
- Post questionnaires to people. With this approach you could either collect the questionnaire later or enclose a stamped addressed envelope. The latter method is costly and experience shows that response rates are rarely above 30%. Another disadvantage is that you will be unable to ask for clarification if some responses are unclear.

Worked example

Two questionnaires: one good and one bad

Location:	**Time:**	**Date:**	**Day of the week:**
Weather conditions:			
Male/Female	**Age:** under 25 years / 26–50 years / over 50 years		
1 How did you travel here today?			
public transport / car / bicycle / motorbike / on foot			
2 On a scale of 1–5 (1 being poor and 5 being best), how do you rate air quality here?			
1 / 2 / 3 / 4 / 5			
3 On a scale of 1–5 (1 being least and 5 being most), which of the following have an impact on air quality in this area?			
vehicles	1 / 2 / 3 / 4 / 5		
factories	1 / 2 / 3 / 4 / 5		
power stations	1 / 2 / 3 / 4 / 5		
residential areas	1 / 2 / 3 / 4 / 5		
4(a) Are you aware of any schemes to improve air quality?			
yes	no		
4(b) If yes, please explain.			
5 What measures, if any, do you think should be undertaken to improve air quality here?			

Table 1.2 Questionnaire 1

ACTIVITIES

11 Identify the type of question in questions 1, 3 and 5.
12 Outline two ways in which the questionnaire could be improved.
13 Suggest how many people should answer the questionnaire to make the results reliable.
14 Suggest, and justify, an appropriate location to undertake the questionnaire.
15 Outline an appropriate strategy to choose the sample to answer the questionnaire.

The environmental impact of a proposed housing development A new housing development of 350 homes is proposed for the south-east edge of the town.
1 Outline the ways in which this proposed development will harm the environment.
2 Explain why air quality will decline
(a) in the short term
(b) in the long term
3 Explain why the new development will lead to a decline in biodiversity.
4 Describe how the new development would have a negative impact on your way of life.
5 Do you think this development is good for the local environment?

Table 1.3 Questionnaire 2

ACTIVITIES

16 Classify the questions into open, closed and scale.

17 Explain why this is an example of a poor questionnaire.

18 Explain why it would be difficult to analyse the results from this questionnaire.

19 Outline ways in which it would be possible to collect more reliable and accurate data (in a questionnaire) on the views of local residents on a proposed development in their home area.

Interviews

Interviews are more detailed interactions than questionnaires. They will generally involve talking to a relatively small number of people. For example, a study of an industrial estate might involve interviews with the directors of six different companies if you were trying to find out why companies chose to locate on the estate. An interview is more of a discussion than a questionnaire, although you should still have a pre-planned question sheet. Interviews enable you to ask open-ended questions that create more in-depth data sets than those afforded by questionnaires. Interviews are thus more likely to produce unexpected responses than questionnaires.

Key definition

Interview – a method of data collection that consists of a series of pre-planned oral questions by the interviewer and oral responses by the research participant.

A good interview will be based on preparatory stages similar to those for a questionnaire. As the number of people interviewed will be relatively small, it is even more important to be able to justify your choice of sample. If you are investigating a controversial issue where there are three obvious interest groups, you will need to ensure that your interviews give equal coverage to each group. It can be a good idea to record interviews, but you should ask the interviewee's permission first. It might be the case that a potential respondent may not be able to offer a face-to-face interview, but is instead willing to offer the opportunity of a telephone interview. This should not present a problem, although it will be important to state that this was a telephone interview in your analysis, and to note any limitations that this mode of communication created compared to your face-to-face interviews.

Safety

Practical work and your IA report must contain a risk assessment. The three main parts of a risk assessment are:

- **hazard identification**: identifying safety and health hazards associated with practical work (see page 24 for diagrams indicating risk factors associated with chemicals)
- **risk evaluation**: assessing the risks involved
- **risk control**: using risk control measures to eliminate hazards or reduce risks.

All fieldwork has potential dangers, even when carried out in a familiar location. An initial survey of the area to be studied may well reveal any potential hazards or dangers before starting the ESS investigation. Common-sense precautions should always be taken, no matter how low the risk appears.

Hazards and risks associated with fieldwork include:

- Terrain, which refers to how the land lies. Variations in terrain may include uneven surfaces, flat areas, hills and steep gradients. It is important to select appropriate shoes.
- Weather conditions can change very quickly in the field. A weather forecast should be consulted before setting out, and appropriate clothing, footwear and supplies selected. In extreme weather, fieldwork may have to be postponed or abandoned.
- Areas where fieldwork is carried out can often be isolated. It is essential you ensure that your school and parents who are not going into the field know the route and your expected time of return.
- Tides can change very quickly. Tide tables should be consulted before setting out. Do not attempt to work on very exposed coasts where unpredictable waves can easily sweep a person off the rocks.

Expert tip

A full risk assessment must be carried out and teacher approval given before embarking on any practical investigation.

Your ESS teacher will advise you of the required clothes and equipment before you undertake an investigation. He or she will also brief students before entering the location to carry out the ESS investigation. However, some good safety advice for any fieldwork includes:

- Warm waterproof clothing should be worn in case of heavy rain. Wear suitable protective footwear to suit the type of habitat you are working in, and wear sunblock and a hat if you are working in sunny conditions.
- Some habitats, such as mountains and tropical rainforests, pose special problems, and work in these habitats must be closely supervised. Particular care and precautions should also be taken when sampling from costal or inland water.
- Obtain advice about the habitat you are planning to study before going into the field. Identify any hazards, such as eroding river banks, tides, sediments or dangerous animals, for example, jellyfish or venomous snakes.
- Take great care when working in or near polluted water. Seal all samples tightly and wash hands in clean water if they come into contact with a polluted water sample. Wear disposable rubber gloves.

Classifying hazardous chemicals

The Globally Harmonized System (GHS) is an internationally adopted system from the United States for the classification and labelling of hazardous chemicals. The GHS provides established description and symbols (Figure 1.17) for each hazard class and each category within a class. This description includes a signal word (such as 'danger' or 'warning'), a symbol or pictogram (such as a flame within a red-bordered diamond), a hazard statement (such as 'causes serious eye damage'), and precautionary statements for safely using the chemical.

Expert tip

Always read the label on a chemical reagent bottle to obtain and review basic safety information concerning the properties of a chemical. It is your responsibility, in conjunction with your teacher, to be fully aware of the hazards and risks of all chemicals you are using.

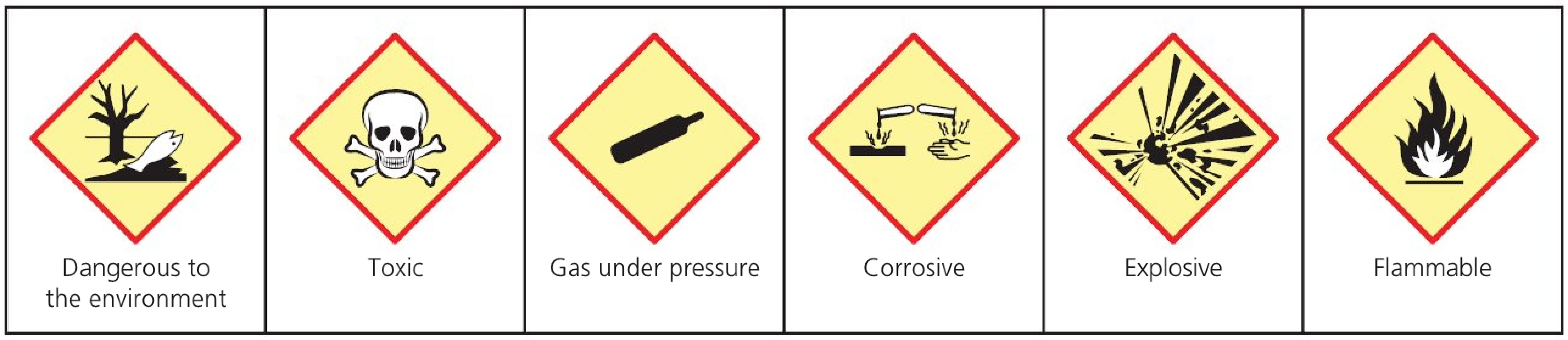


Figure 1.17 Hazard warning signs

Safety Data Sheets

The Safety Data Sheet (SDS) is provided in the US by the manufacturer, distributor, or importer of a chemical to provide information about the substance and its use. The SDS presents the information in a uniform manner and includes the properties of each chemical, the physical health, and environmental health hazards, protective measures and safety precautions for handling, storing, disposing of and transporting the chemical.

Expert tip

When carrying out fieldwork you must follow the IB ethical practice guidelines and IB animal experimentation policy – that is, animals and the environment should not be harmed during your work. You need to consider the impact of your investigation on any organisms you are studying and the environment they live in, if relevant to your study.

Environmental and ethical assessment

The IB Organization has an animal experimentation policy which gives strict guidelines for all practical work undertaken as part of the Diploma Programme. Under this policy:

- No fieldwork or experiments will be undertaken that damage the environment.
- No experiments involving other people will be undertaken without their written consent and their understanding of the nature of the experiment.
- No experiments will be undertaken that cause distress to, or inflict pain on, live animals or humans.

Whole plant specimens should not be picked or uprooted from their natural environment. If your proposed work requires the use of leafy stems and flowers, you should ensure that they are obtained from gardens or from commercial sources or bred for the purpose. Great care must be taken to ensure that plants are not trampled or damaged during the sampling process.

It is not acceptable to carry out experiments that measure the size or strength of force or heat needed to dislodge limpets or other molluscs from rocks. Any animal removed from its environment for the purpose of counting or measurement should be returned as soon as possible. Particular care should be taken when sampling invertebrates found in rivers, ponds and on rocky shores. Some investigations may involve the use of 'mark/recapture' sampling (Chapter 2, page 30). Before this is carried out, consideration should be given to the effects upon individuals and populations of the organism.

Some ecological investigations may involve the use of pitfall traps (Chapter 2, pages 32–33). These traps should be checked several times daily to ensure animals are not trapped for long periods of time. The animals should be given protection from the prevailing weather and also a source of suitable food and water.

Expert tip

A full ethical and environmental assessment must be carried out and teacher approval given before embarking on any practical investigation.

Expert tip

When assessing safety, ethics and environmental issues, you should ensure that the following are considered:

- evidence of a risk assessment
- an appreciation of the safe handling of chemicals or equipment (for example, the use of protective clothing and eye protection), if relevant
- application of the IBO animal experimentation policy
- a reasonable consumption of materials
- use of consent forms when people are involved in your investigation
- correct disposal of waste
- attempts to minimize the impact of the investigation on field sites.

2 Ecology and ecosystems

Terminology

Ecology is the study of the interaction between organisms and their environment. As in all science, the terms used to frame and discuss ecology have specific meanings. Words must be used carefully and in the right context when writing your IA and answering exam questions.

The smallest biological unit that an **ecologist** tends to study is the species (although increasingly work on **DNA** is being used to examine the differences between species and populations). The largest biological unit studied in your ESS course is the ecosystem.

- A **species** is a group of organisms that can potentially interbreed to produce fertile offspring.
- A **population** is defined as a group of individuals of the same species (Figure 2.1).

Figure 2.1 A population of ants on Brownsea Island

- A **community** is all the populations of different species living together and interacting with each other.
- Communities form the **biotic** (or living) part of an ecosystem, and the **abiotic** components (such as rocks, water, light and air) comprise the non-living part.
- An **ecosystem** is formed by the interaction between communities and their abiotic environment.
- The **environment** can be defined as the external surroundings that act on an organism, population or community and influence its survival and development.

Life can therefore be seen as organized within a hierarchy, from a species comprised of many individuals that form populations, populations which interact with other species' populations to form communities, and communities which interact with the abiotic environment to form ecosystems. The place a species lives is called its **habitat** and a complete description of a species' ecology, that is, where, when and how it lives, is called its **niche**

Limiting factors are components of an ecosystem, either biotic or abiotic, that limit the distribution or numbers of a population. Biotic limiting factors include interactions between organisms such as competition or predation, and abiotic limiting factors include physical components of the environment such as temperature, salinity, pH, oxygen, carbon dioxide, light, hydrostatic pressure, water current, wind velocity, substratum type, rainfall amount and humidity.

Key definitions

Ecologist – a scientist who studies ecology.

DNA – the genetic basis of life.

Measuring abiotic factors of the system

Abiotic factors include:

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

Standardized methods are needed to compare ecosystems, as described in Table 2.1.

Abiotic factor	Equipment	How the factor is measured
Wind speed*	Anemometer	Hold the anemometer so it is facing into the wind, at a set distance above the surface (Figure 2.2).
Temperature[+]	Thermometer	Put the thermometer at a set distance beneath soil or below water.
Humidity*	Hygrometer	Put the digital hygrometer at a set distance above the ground, or on the ground, and leave to equilibrate. Measure the humidity once the reading has stabilized (Figure 2.3).
Light[+]	Light (or lux) meter	Put the light meter at a set distance above the surface of or below the water (Figure 2.3).
Soil compaction*	Penetrometer	A metal bolt with a pointed end is dropped from a set height within a guide sleeve (Figure 2.4) – the depth of penetration of soil indicates compaction.
Flow velocity[x]	Flow meter	Put the impeller at a set distance below the water and count revolutions per minute (Figure 2.5).
Turbidity[†]	Secchi disc	Lower the disc until the markings are no longer clearly visible.
Dissolved oxygen concentration (in ppm)[x]	Dissolved oxygen meter	Submerge the oxygen meter/probe at a fixed distance beneath surface. Record measurements over a set period of time and calculate an average.
Soil moisture*	Evaporate water; soil moisture probes	Weigh the soil, then put in a hot oven and continually reweigh until there is no longer any loss in mass. Percentage moisture is then calculated using the formula: *Percentage moisture* $\frac{\textit{original mass} \quad \textit{final mass}}{\textit{original mass}} \times 100$

Table 2.1 The measurement of abiotic factors in ecosystems. Each measurement should be repeated several times and then precise results averaged to improve reliability. Type of ecosystem where technique is mainly used: *terrestrial; [x]freshwater; [†]marine; all three

Key definition

Abiotic factor a non-living physical factor that can influence an organism or ecosystem, for example, temperature, sunlight, pH, salinity or precipitation.

Expert tip

Oxygen, and other solutes present in very low concentrations in solution, is measured in parts per million concentration (ppm). This is another non-SI unit of measurement (Chapter 1, page 12), concerning weight per volume (w/v) concentration.

Expert tip

When carrying out ecological studies, it is not possible to control all the variables that may affect your dependent variable. In these instances, the other variables can be monitored, so that their potential effect on the dependent variable can be determined (see page x).

Figure 2.2 Using an anemometer to measure wind speed in a shingle ridge succession

Figure 2.3 A light (or lux) meter (top) and hydrometer (being held) measuring light intensity and relative humidity respectively on a shingle ridge succession

Figure 2.4 Using a simple penetrometer to measure soil compaction

Figure 2.5 Using a flow meter to measure water speed in a forest river

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 pages 139–140:

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

Soil moisture

Soils contain water and organic matter. Weighing samples before and after heating in an oven gives the mass of water evaporated and therefore moisture levels. Repeated readings should be taken until no further mass loss is recorded – the final reading should then be used. Loss of mass can be calculated as a percentage of the starting mass.

Figure 2.6 Taking a soil sample from a shingle ridge succession. Other variables being monitored include light (red light meter at top of photo), soil temperature and wind velocity (bottom of photo)

Expert tip

When using a flow meter, the impeller should be at a deep enough level to be submerged by the stream water. The impeller should be facing into the flow of water (Figure 2.5).

Expert tip

You need to be able to evaluate methods you use to measure abiotic factors in an ecosystem.

Expert tip

If the oven is too hot when evaporating the water, organic content can also burn off, releasing oxides of carbon, further reducing soil mass and giving inaccurate readings.

Worked example

When performing calculations, all of your steps must be shown. It is good practice to include units in your working, where appropriate. Below is an example of a calculation showing how the percentage of water in moist soil can be determined.

Mass of evaporating basin	200 g
Mass of evaporating basin and moist soil	250 g
Hence, mass of moist soil	250 g – 200 g = 50 g
Final mass of evaporating basin and dry soil	240 g
Hence, loss in mass	250 g – 240 g = 10 g
Percentage of water in moist soil	$\frac{(10 \times 100)}{50} = 20\%$

Expert tip

You need to be able to evaluate sampling strategies.

Common mistake

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

■ ACTIVITY

1 Evaluate the use of equipment to measure abiotic factors in freshwater, marine and terrestrial ecosystems.

Ideas for investigations

You could compare organic soil content from different areas of an ecosystem. Areas can be selected according to their canopy cover (that is, open areas versus more closed areas), vegetation type (tree versus shrub) or location across an ecological gradient (that is, deep forest through to forest edge), for example.

The **organic content** of soil can be measured by first drying the soil and then burning off the organic content in an oven.

Two areas need to be sampled. Make sure that all the other factors (controlled variables, in this case vegetation, gradient, human impact and weather) are the same.

- Five sample sites need to be randomly chosen in each sample area, with five soil samples taken at random from each sample site. This makes a total of 25 soil samples taken from each area, so as to ensure the readings are reliable.
- Collect the samples from a depth of 5 cm below the surface to ensure that the soils have not been affected by surface processes.
- Place each soil sample in an airtight food bag, close the bag and give it a label.
- Weigh each individual soil sample and record its mass (S).
- Place it in an oven and heat it at 100 °C for 24 hours, taking care not to have the temperature so high that organic matter is burnt.
- Repeat the procedure until there is no change in mass – the soil is completely dry.
- Crush the soil until it is a powder, using a pestle and mortar.
- Place . 6 g of dried soil from each sample into a crucible.
- Heat the soil using a Bunsen burner and then reweigh each individual sample (S_2). This process will burn off the organic content of the soil sample. Ensure that the lab is well ventilated.
- To calculate the organic content, subtract the mass after burning from the mass before burning (S_1 S_2). Carbon content can be estimated as making up 50% of the organic content, that is:

  Carbon content = $\frac{(S \quad S_2)}{}$

Key definition

Organic content – carbon-containing content.

Expert tip

During your write-up, use of the word 'about' should be avoided, as in 'We took about 100 g of topsoil ...'. If the quantity of soil needs to be weighed accurately then this should be stated, but if the mass is not critical then the term 'approximately' should be used.

Ideas for investigations

1 Determining the volume of air in soil

Pour water from a measuring cylinder into a metal can to find the volume of the can. Pour two cans full of water into a large jar and mark the water level with a marker pen on the outside of the jar.

Pour enough water from the jar back into the can to just fill it and mark the new water level in the jar. The two marks on the jar now represent the volume of one and two cans. The jar should be left with water up to the one can mark.

Empty the can and press it, open end down, into some soft soil. Stamp the can down until its base is level with the soil surface. Dig the can out carefully and remove any surplus soil from the mouth of the can.

Use a stick to dig out the soil and let it fall into the jar of water. Since there is air in the soil, the new water level will be below the two-can mark. Fill the measuring cylinder to the top with water and pour the water into the jar until the level reaches the two-can mark. Note the reading in the measuring cylinder so you can calculate the volume of water you have added. This is the same as the volume of air which escaped from the soil.

2 Comparing the permeability (porosity) of soil

Plug the stems of two glass funnels with glass wool and half fill one with a soil sample and the other with an equal volume of another soil sample. Cover both soil samples with water and keep the levels the same by topping up during the experiment. Collect the water that runs through in a given time in a measuring cylinder. A measurable difference will be observed if two very different soil samples are used, for example, a sandy soil and a clay soil.

3 Measuring the pH of soil

Place about 1 cm of soil in the bottom of a test tube or boiling tube. Add about 1 cm of barium sulphate powder. This is a neutral salt that will precipitate any clay present in the soil so that the colour of the solution can be seen. Then add 10 cm of distilled water and 2 cm of universal indicator solution to the tube. The mouth of the tube is closed with a bung and the tube shaken vigorously. The tube should be allowed to stand for a minute and a clear-coloured solution should appear at the top of the soil as the soil particles settle. Hold the tube against a colour chart; its colour will correspond to a particular pH or pH range.

Measuring biotic factors of the system

Standardized methods are needed to compare **biotic factors** of ecosystems with one another. Such studies also allow ecosystems to be monitored and evaluated over time and for the effects of human disturbance to be understood.

Keys

Your investigation may require you to identify and name different terrestrial or marine animals or plants. One approach may be to use a book that has photographs of groups of related animals and plants to identify them. Another approach is to use a biological key. Any keys or books that you plan to use in the identification of animals or plants should be outlined in your plan and later referenced in your bibliography (see page 174).

Naming organisms

Binomial names should be used to describe organisms. For example, *Cardamine pratensis* is the binomial name for an English flower known as the 'cuckoo flower' or 'lady's smock'. The first name in the binomial name is the genus (group of closely related species) and the second name is the species name. The binomial name is always given in Latin and italicized.

Key definition

Biotic factor – a living physical factor, such as a species, population or community, that influences an ecosystem.

Expert tip

When carrying out fieldwork, you must follow the IB ethical practice guidelines and IB animal experimentation policy: that is, animals and the environment should not be harmed during your work.

Figure 2.7 This photo shows a dichotomous key for identifying aquatic invertebrates, developed by the Field Studies Council Centre at Slapton Ley, UK

Key definition

Binomial – literal meaning, 'two names'. The first name gives the genus and the second gives the species.

Methods for estimating the abundance of organisms

It is not possible to study every organism in an ecosystem, so limitations are put on how many plants and animals are studied. Trapping methods enable limited **samples** to be taken. The way in which the abundance of an organism is measured depends on whether it is **motile** or **non-motile**.

> **Key definitions**
>
> **Sample** – a subset of a whole population or habitat used to estimate the values that might have been obtained if every individual or response was measured.
>
> **Motile** – an organism that can actively move from place to place.
>
> **Non-motile** – an organism that cannot move or, for the purposes of sampling, can only move very slowly (such as limpets on a rocky shore).

Lincoln index

This technique is known as the capture–mark–release–recapture method. It is used for estimating the population size of motile 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, snail shells 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 the first day

n_2 = number of animals captured on the second day

m = number of marked animals recaptured on the second day.

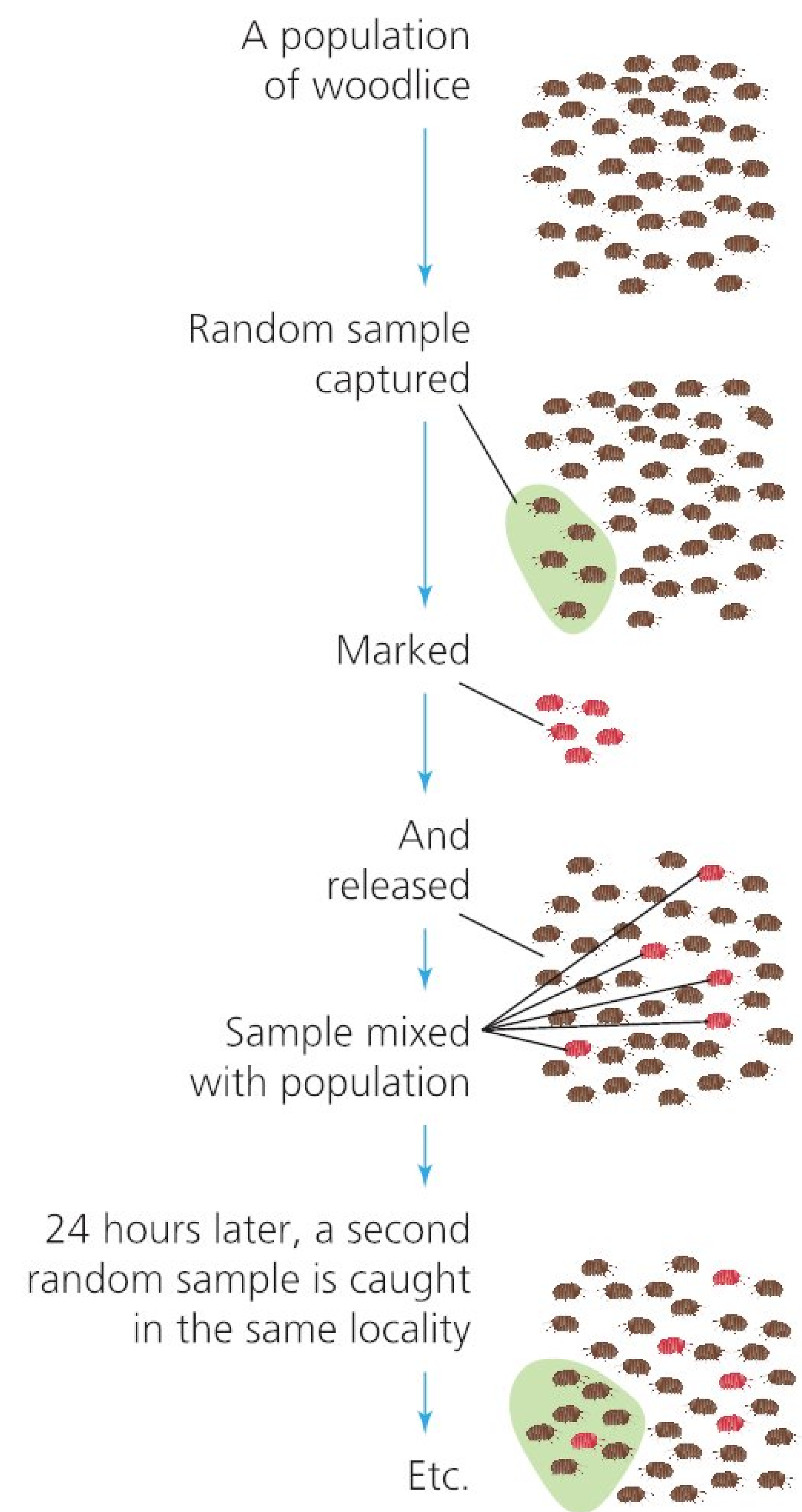


Figure 2.8 Estimating animal populations using mark, release and recapture. Here: $N = \frac{5 \times 8}{1} = 40$

Expert tip

There are several limitations to the Lincoln index method of estimating population size. The method assumes that the population is closed, both geographically and in terms of population numbers; animals may move in and out of the sample area, however, and new individuals may be born and others die. The method also assumes that all animals are equally likely to be captured in each sample, which may not necessarily be the case. The density of the population in different habitats might vary: there may be many in one area but few in another.

Ideas for investigations

Invertebrates make good organisms for carrying out determination of the Lincoln index. Snails can be marked with enamel paint on their shells (using a colour that is not obvious to predators). Damselflies can be marked on their wings using a permanent marker. Disturbed and undisturbed habitats containing such species can be compared to see how human activities affect population size.

ACTIVITY

2 Describe the way the capture–mark–release–recapture method is used to estimate population size using a named animal species.

Quadrat methods

Quadrats are used for estimating the abundance of plants and non-motile animals, or for sampling motile animals from a fixed area in a set period of time (see Figure 2.9).

> **Key definition**
>
> **Quadrat** – a square frame which outlines a known area for the purpose of sampling.

- Quadrats are placed according to random numbers, after the area has been divided into a grid of numbered sampling squares. The presence or absence in each quadrat of the species under investigation is then recorded.
- **Percentage frequency** is the percentage of quadrats in an area in which at least one individual of the species is found. It is calculated by taking the number of occurrences and dividing by the number of possible occurrences; for example, if a plant occurs in 3 out of 100 squares in a grid quadrat, then the percentage frequency is 3%.
- **Percentage cover** is the proportion of a quadrat covered by a species, measured as a percentage. It is calculated 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.

1 A map of the habitat (e.g. meadowland) is marked out with gridlines along two edges of the area to be analysed.

2 Coordinates for placing quadrats are obtained as sequences of random numbers, using computer software, or a calculator, or published tables.

3 Within each quadrat, the individual species are identified, and then the density, frequency, cover or abundance of each species is estimated.

4 Density, frequency, cover or abundance estimates are then quantified by measuring the total area of the habitat (the area occupied by the population) in square metres. The mean density, frequency, cover or abundance can be calculated using the equation:

$$\text{population size} = \frac{\text{mean density (etc) per quadrat} \times \text{total area}}{\text{area of each quadrat}}$$

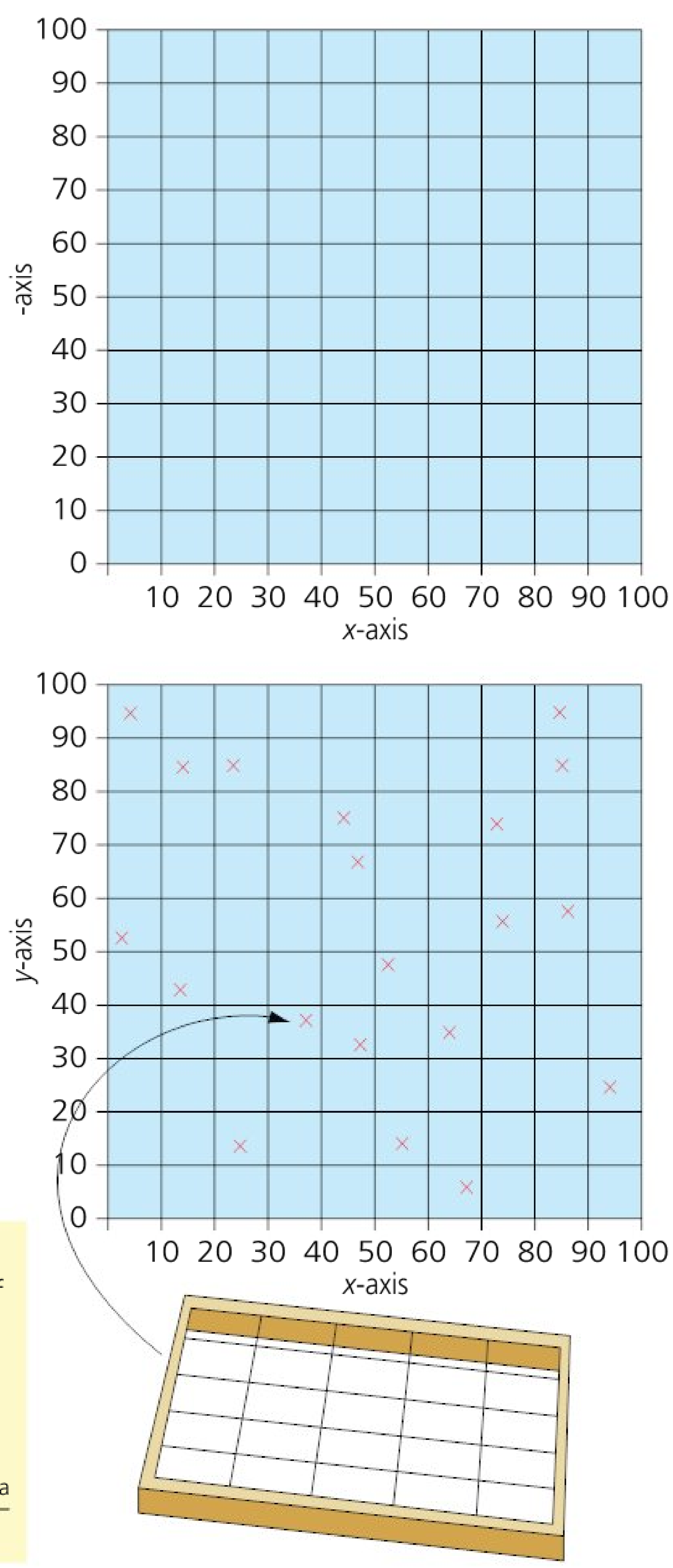


Figure 2.10 Random locating of quadrats

It is not possible to measure all organisms in an ecosystem and so a sample must be taken. The **sample size** is the number of samples taken from a population. 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 areas which contain two or more different habitat types. For example, if an area of woodland is being studied, there are likely to be different types of habitat within it: random sampling may miss one or more of these and so stratified sampling is used. This technique takes into account the proportional area of each habitat type within the woodland and samples each one accordingly. The technique can also be used to compare undisturbed and disturbed areas.

Expert tip

As a rule of thumb, once five quadrats have failed to show any new species it may be assumed that no further species will be found. However, when an assumption such as this is made it must be stated in your investigation report as it may affect the reliability of the results.

Figure 2.9 A quadrat being used to estimate the species richness of leaf-litter invertebrates in a temperate forest ecosystem

Key definitions

Sample size – the number of samples taken from a population.

Random sampling – a method of choosing a sample from a population without any bias.

Expert tip

Random sampling ensures that every individual in the community has an equal chance of being selected and so a representative sample is very likely.

- **Systematic sampling** is used along a **transect** where there is an environmental gradient, such as the change from the edge of a woodland, adjoining open land, into interior forest where, for example, warmer and lighter conditions predominate at the edge of the forest while cooler and darker ones predominate the interior.

Key definition

Transect – arbitrary line through a habitat, selected to sample the community.

Expert tip

Quadrats must be placed randomly to avoid sampling bias. Subjective choice of location for quadrats would lead to samples that are not representative of the area they are sampling. For example, areas that have a large number of species may be chosen at the expense of those with less species richness. Random allocation of sampling sites should always be used when a uniform habitat is being sampled.

Expert tip

If you have an iPhone, you can convert it into a scientific calculator by turning it sideways (that is, 'landscape') when in calculator mode. The scientific calculator has a random number generator function.

Ideas for investigations

Sampling strategies may be used to measure biotic and abiotic factors and their change in space, along an environmental gradient or before and after a human impact, for example.

Point quadrat

This is a frame bearing ten holes through each of which a pin is passed (Figure 2.11). It is particularly useful in transect studies of overgrown habitats where several plant species may overlap. All species touched by the pin as it descends to the ground are recorded for each of the holes.

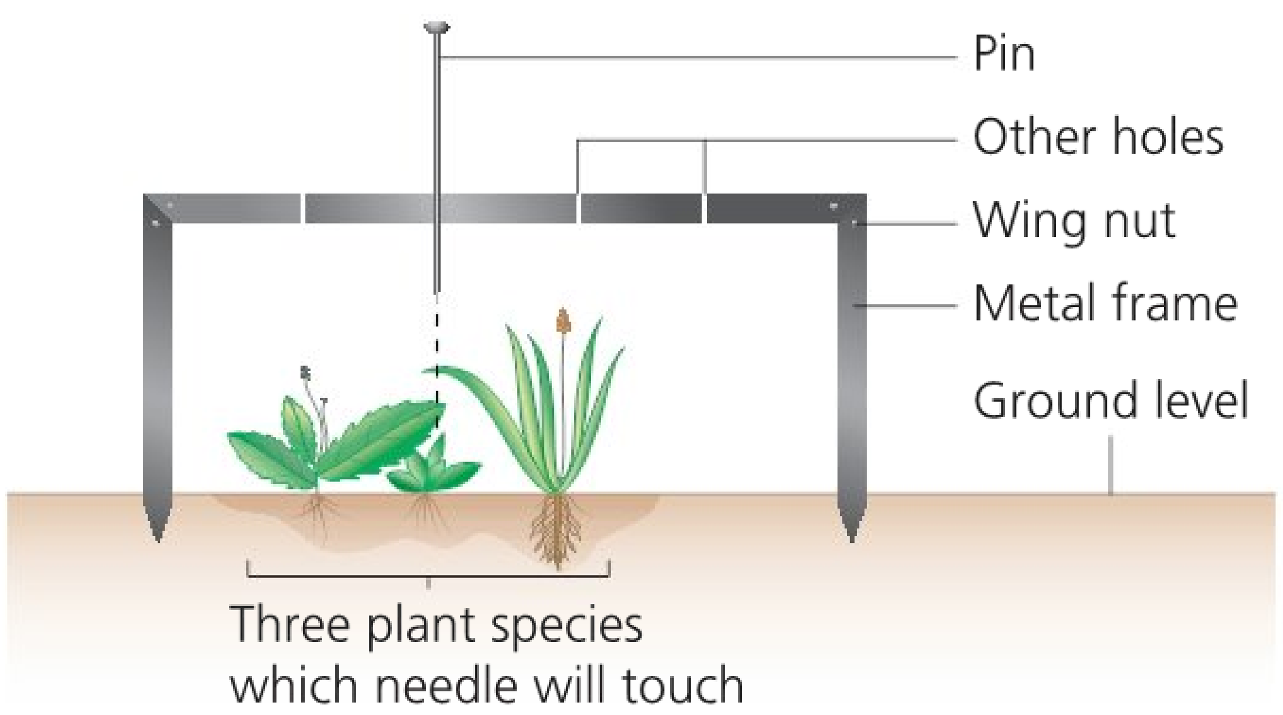


Figure 2.11 Point quadrat or pin frame

Methods for sampling motile animals

Sampling methods must allow for the collection of data that is scientifically representative and appropriate, and allow the collection of data on all species present. Results can be used to compare ecosystems. Trapping methods for organisms that are motile include:

- **pitfall traps**: beakers or pots buried in the soil which animals walk into and cannot escape from (Figure 2.12)
- **nets**: for example, an aquatic kick net (Figure 2.13) or butterfly net
- **flight-interception traps**: fine-meshed nets that intercept the flight of insects; the animals fall into trays where they can be collected
- **light traps**: a UV bulb against a white sheet attracts certain night-flying insects (Figure 2.14)
- **quadrats**: these can be used to sample small animals from a fixed area within a specific period of time, for example, leaf-litter invertebrates (Figure 2.9 on page 31).

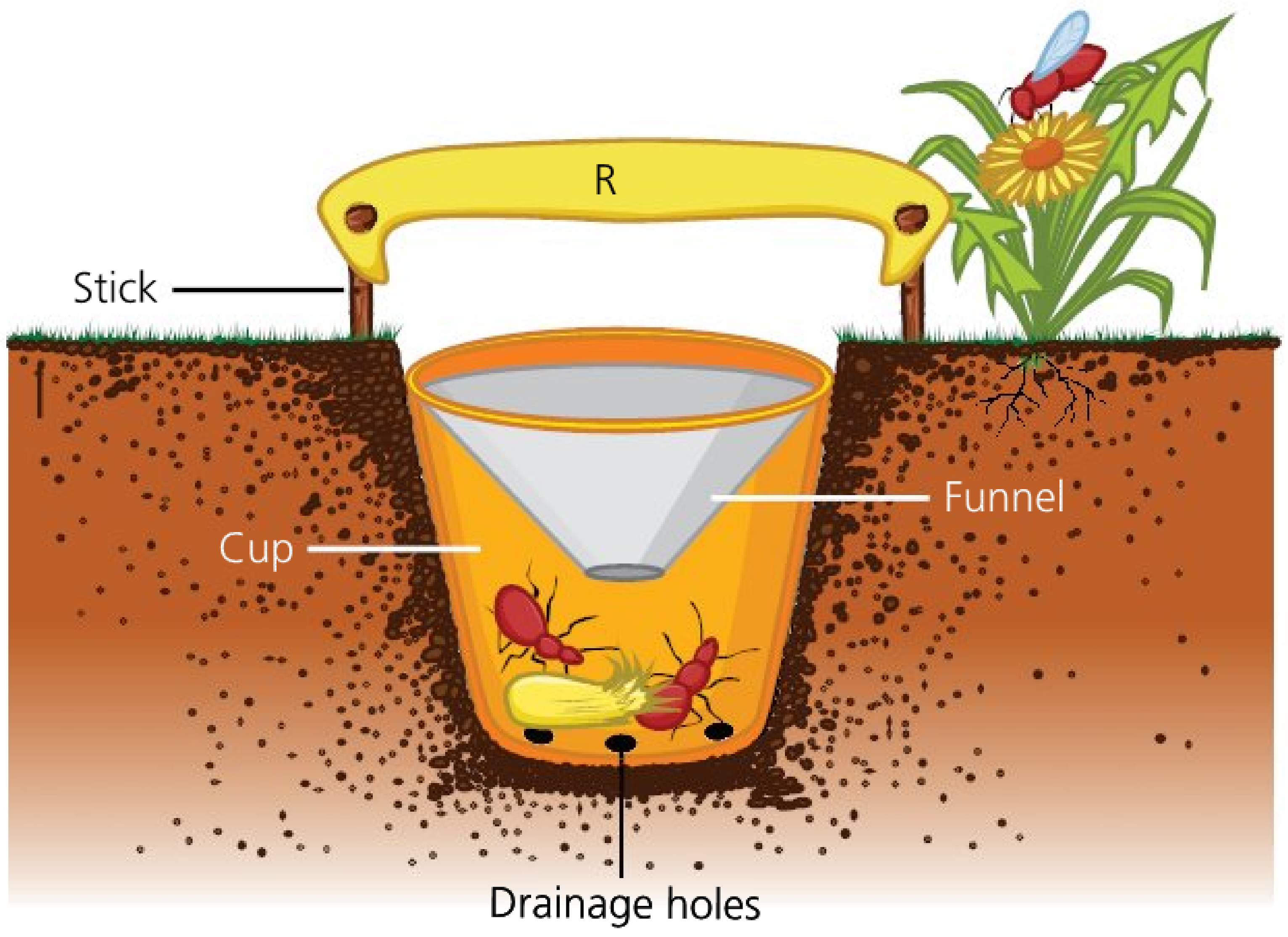


Figure 2.12 A pitfall trap

Figure 2.13 Using an aquatic kick net to sample aquatic invertebrates from a pond

Figure 2.14 Insect light trap

The study of animal abundance and distribution may provide a suitable topic for an individual investigation, provided the IB animal experimentation policy is complied with. In particular:

Experiments involving animals must be based on observing and measuring aspects of natural animal behaviour. Any experimentation should not result in any pain or undue stress on any animal (vertebrate or invertebrate) or compromise its health in any way. Therefore experiments that administer drugs or medicines or manipulate the environment or diet beyond that easily tolerated by the animal are unacceptable. Experiments resulting in the death of any animal are unacceptable

Source: © IBO 2009

■ Leaf-litter invertebrates

If the leaf litter on a forest floor is to be sampled, a standardized sample of leaf litter (selected using a quadrat – Figure 2.9 on page 31) can be put in a tray and a pooter used to suck invertebrates into a small pot (Figure 2.15). Pooters can also be used to sample insects directly from vegetation. Pooters can be bought or made using a glass jar or plastic pot with tubes or straws.

Pitfall traps can also be used to sample invertebrates (Figure 2.12). Insects fall into the trap and the funnel stops them from escaping. Pitfall traps should be humane and not kill the insects being sampled. Pitfall traps should be regularly monitored and emptied to avoid invertebrate mortality.

Figure 2.15 Two pooters with different sized collection chambers. One tube is used to create suction (this tube has a mesh on the other end to avoid animals being drawn into the mouth) and the other to collect invertebrates

Ideas for investigations

The number of species (or **diversity** – see Chapter 3, page 44) of leaf-litter invertebrates can be compared in areas that contain native or non-native species of tree (for example, in the UK, oak is a native species and sycamore a non-native species). The species richness of insects, spiders and other invertebrates can be expected to be higher in woodland containing native species, because feeding relationships between the tree and insects that form part of the food chain linking them have had longer to establish.

Sampling aquatic animals

In order to sample river organisms, the bed of the river is disturbed so that animals found there can be collected. The method involves agitating the riverbed with a boot and collecting disturbed animals downstream in a net. A fixed time is set for this 'kick sampling' (Figures 2.13 and 2.16). The catch is put in a shallow white tray with at least 2 cm depth of water (Figure 2.17). An identification key is used to sort the catch into different groups (Figure 2.7 on page 29).

Limitations to this method include the difficulty of standardizing the kick action (different intensities and times of kicking will disturb different numbers of organisms) and some animals may remain stuck to rocks and so not be sampled.

Figure 2.16 Kick sampling, used to sample aquatic invertebrates from a forest stream

Ideas for investigations

1 **Analysing sediment particle size**

Disturbed areas of forest can be expected to have increased rates of sedimentation into streams and other bodies of water from surrounding land, due to the vegetation that normally holds the soil in place being removed or compromised. Sediment particle size collected from stream beds can be analysed using sieves with different mesh sizes. If aquatic invertebrates are also collected, using the kick-sampling method, sediment particle size can be correlated with invertebrate species richness or diversity to see if human impacts can be linked to survivorship in stream animals.

2 **Analysing the organic content of stream water**

Samples of water are taken from different positions in a stream for analysis in the lab. Looking at areas with more overhanging vegetation versus more open areas may provide a good comparison.

- Pour the water sample through filter paper to remove solid organic sediments. Keep the water for further processing.
- Record the mass of the filtered sediment using an analytical electronic balance.
- Place the sediment in a crucible and strongly heat using a Bunsen burner. Ensure that the lab is well ventilated.
- Calculate the difference between the mass before burning and the mass after burning. This difference is the organic content.
- Carbon content can be estimated as making up 50% of the organic content.
- The water from each sample can be further tested using a **colorimeter** (it may have to be diluted with distilled water) or a **spectrophotometer**
- Dissolved organic content may be contained within the water, altering the colour of the water. The **absorbance** of samples from different parts of the river can be compared to determine differences in dissolved organic content.

Figure 2.17 Identifying aquatic invertebrates collected from a forest stream. A sample obtained using a kick net is put into a white tray; individual specimens can be identified and separated into different species using an artist's palette (left from tray)

Expert tip

Absorbances can only be measured accurately with dissolved substances. Insoluble particles will scatter light and interfere with the technique.

Key definitions

Colorimeter – an instrument for measuring the absorbance of a solution using visible light.

Spectrophotometer – an instrument for measuring the absorbance of a solution using ultraviolet radiation or visible light.

Absorbance – a measure of the light absorbed by the sample that does not reach the detector. It is proportional to concentration of dissolved solute.

Method for estimating the biomass of trophic levels

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 killing living organisms (although not all the organisms in an area need to be sampled – see below).
- Problems exist with measuring the biomass of very large plants such as trees, and with roots and underground biomass.

Calculating dry weight biomass

To obtain quantitative samples, biological material is dried to constant mass:

- The sample is weighed in a container of known mass.
- 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 (for example, 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 recorded.
- This mass is multiplied by the total number of organisms to estimate the total biomass.
- This is called an **extrapolation** technique.

Expert tip

Data from methods for estimating biomass can be used to construct ecological pyramids. Pyramids are used to show data from successive trophic levels (producers, primary consumers, secondary consumers, etc). To produce a pyramid of numbers, all the organisms in a specific area are sorted into their trophic level and the total numbers in each level recorded. The numbers present in each trophic level are represented on the graph paper by a horizontal bar. The bar for the producers is at the bottom, the bar for primary consumers is on top of this bar, etc. The bars are of the same depth and the length is proportional to the sample size. The bars are aligned so that the final pyramid is symmetrical. In a pyramid of biomass, the organisms in each trophic level are weighed and expressed on the graph paper as grams per square metre ($g\,m^{-2}$

Ideas for investigations

Energetics data can be obtained online for different organisms (for example, the amount of energy contained within one gram of biomass for different species), for instance, **https://www.int-res.com/articles/meps/39/m039p243.pdf** and **https://www.researchgate.net/publication/259733644_A_generalized_model_for_estimating_the_energy_density_of_invertebrates.** Collections of live specimens can, in this way, be used to estimate the biomass of different trophic levels and different ecosystems (for example, disturbed and undisturbed) can be compared. The organisms sampled are returned to the wild once population numbers and species richness are established.

Key definition

Biomass – the mass of organic material in organisms or ecosystems, usually stated per unit area.

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 the average biomass is calculated.

ACTIVITIES

3 Describe and evaluate methods for measuring **three** abiotic factors in a forest ecosystem.
4 Explain the difference between percentage frequency and percentage cover.
5 State which data are needed to estimate the size of an animal population. Write the equation needed to calculate the population size.
6 Explain how biomass is calculated.

Measuring productivity

Primary productivity

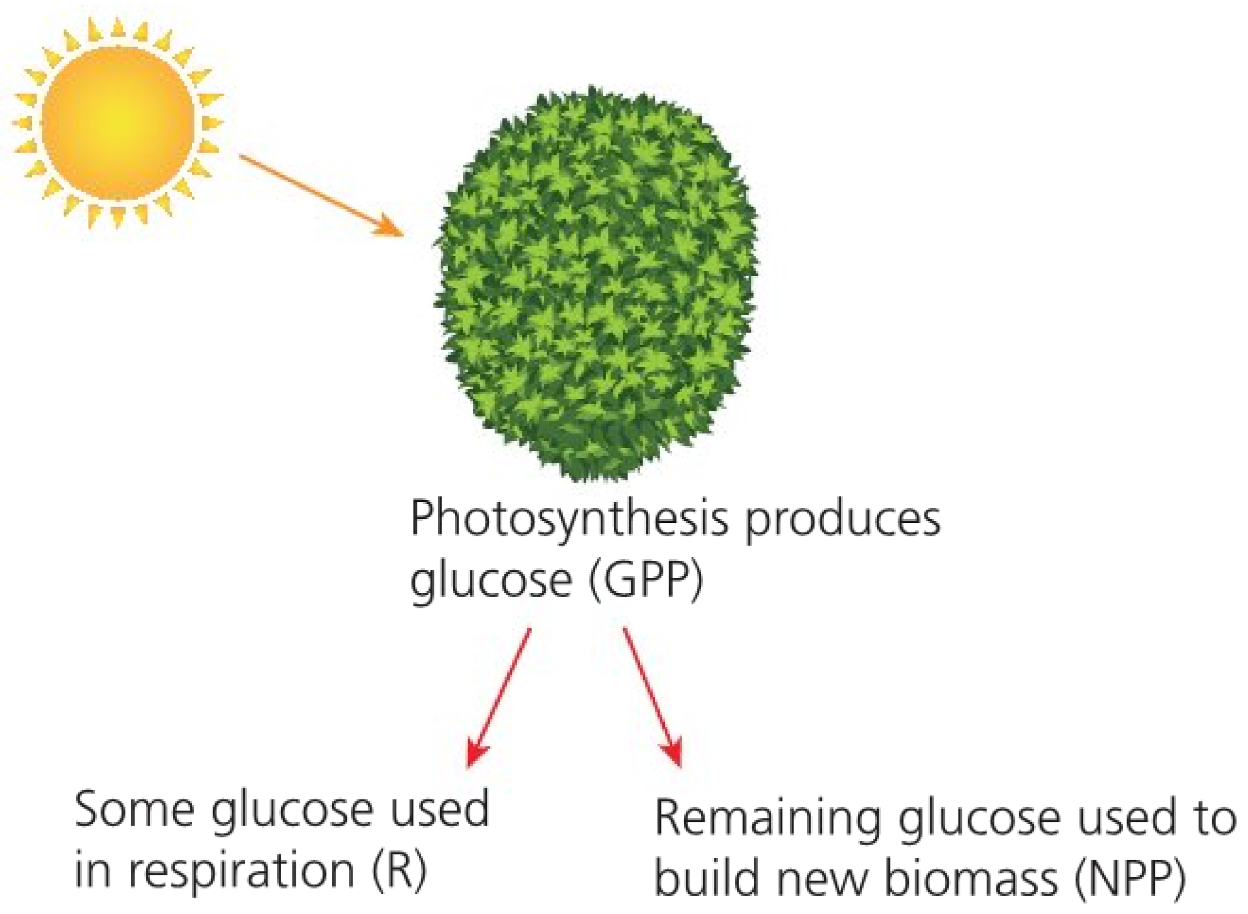


Figure 2.18 The difference between gross primary productivity (GPP) and net primary productivity (NPP)

The easiest way to measure **gross primary productivity (GPP)** and **net primary productivity (NPP)** is by using aquatic plants. To calculate GPP and NPP, measurements of photosynthesis and respiration need to be taken. Photosynthesis and respiration either produce or use oxygen. Measuring **dissolved oxygen** will therefore give a measurement of the relative rates of photosynthesis and respiration in aquatic plants.

Net primary productivity can be calculated by measuring the **increase** in dissolved oxygen when aquatic plants are put in the light. In the light both photosynthesis and respiration will be occurring, but the rate of photosynthesis will be greater than the rate of respiration.

Net primary productivity can be calculated using the equation:

NPP = GPP – R

where R = respiratory loss.

Respiration can be calculated by measuring the **decrease** in dissolved oxygen when aquatic plants are put in the dark. In the dark only respiration will be occurring and not photosynthesis. The equation can thus be rearranged to calculate GPP:

GPP = NPP + R

Key definitions

Gross primary productivity (GPP) – the total gain by producers in biomass made through photosynthesis, measured in a specific area in a specific period of time.

Net primary productivity (NPP) – the gain by producers in biomass once energy from respiration has been removed, measured in a specific area in a specific period of time.

Worked example

Experiment to calculate gross primary productivity and net primary productivity in an aquatic plant

Productivity can be measured using an aquatic plant. The plant was put in light and dark conditions. Dissolved oxygen was measured before and after the plant was put in light and dark conditions. In this experiment gross primary productivity

Expert tip

Temperature needs to be controlled since gas solubility varies with temperature.

(GPP) and net primary productivity (NPP) were recorded by using measured changes in dissolved oxygen in milligrams of oxygen per litre per hour. Sample results follow:

Plant in the light

Concentration of dissolved oxygen at the start of the experiment = 10 mg of oxygen per litre.

Concentration of dissolved oxygen at the end of the experiment = 12 mg of oxygen per litre.

Increase in dissolved oxygen = 2 mg of oxygen per litre.

The increase in dissolved oxygen is a measure of NPP. The experiment lasted one hour and so the **NPP = 2 mg of oxygen per litre per hour.**

Plant in the dark

Amount of dissolved oxygen at the start of the experiment = 10 mg of oxygen per litre.

Amount of dissolved oxygen at the end of the experiment = 7 mg of oxygen per litre.

Loss of dissolved oxygen = 3 mg of oxygen per litre per hour.

The loss of dissolved oxygen is a measure of respiration (R).

NPP = GPP – R, so GPP = NPP + R

Therefore **GPP** = 2 mg + 3 mg = **5 mg of oxygen per litre per hour.**

Secondary productivity

Gross secondary productivity (GSP) can be defined as the total gain by consumers in biomass through absorption. Gross secondary productivity is measured in units of mass in a specific area in a specific period of time.

Gross secondary productivity = food eaten – faecal loss

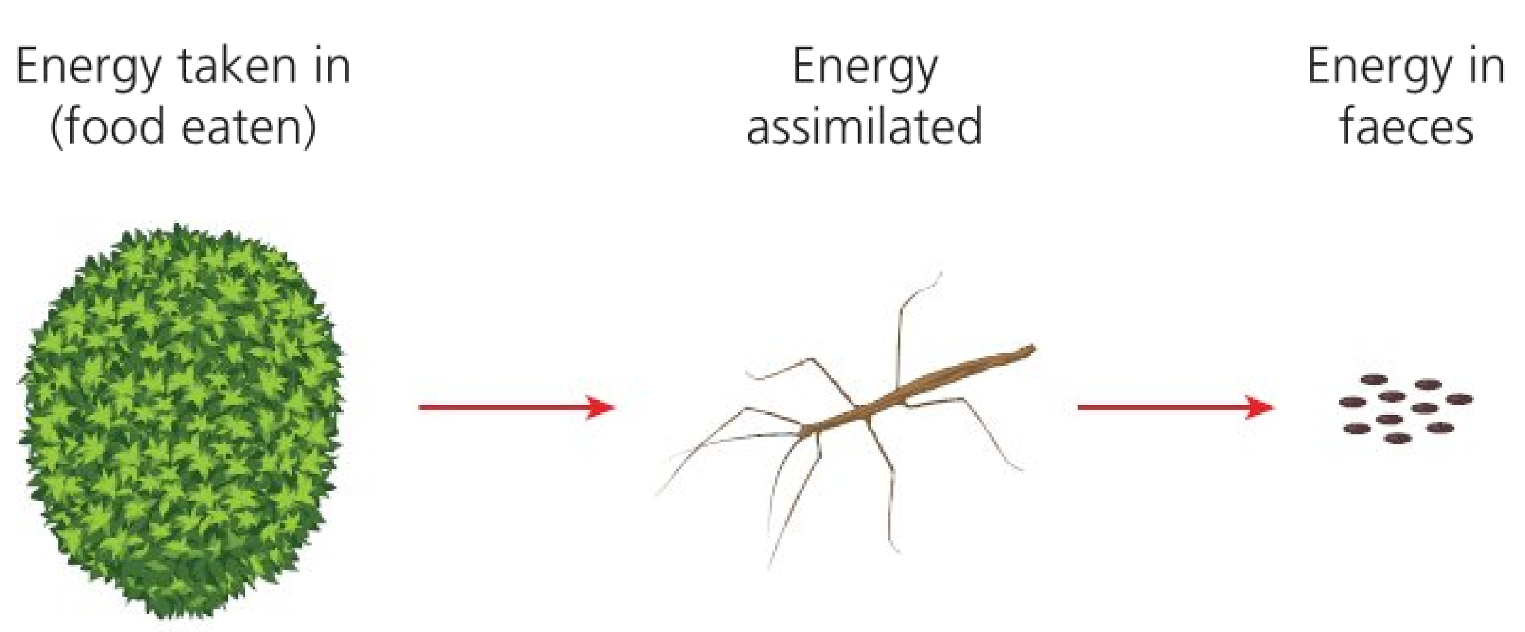


Figure 2.19 Gross secondary productivity

Net secondary productivity (NSP) can be defined as the gain by consumers in biomass once energy from respiration has been removed. Net secondary productivity is measured in units of mass in a specific area in a specific period of time.

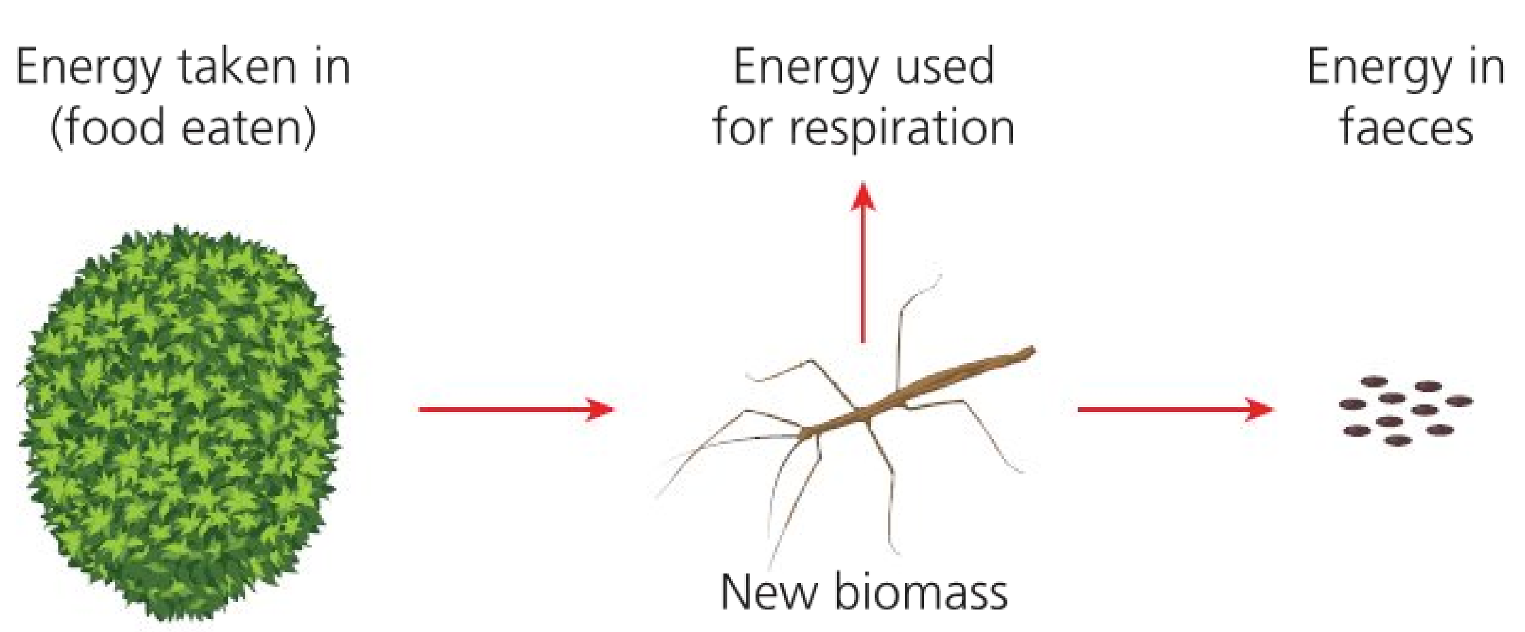


Figure 2.20 Net secondary productivity

Key definitions

Gross secondary productivity (GSP) – the total gain by consumers in biomass through absorption. Gross secondary productivity is measured in a specific area in a specific period of time.

Net secondary productivity (NSP) – the gain by consumers in biomass once energy from respiration has been removed. Net secondary productivity is measured in a specific area in a specific period of time.

Worked example

Experiment to calculate values of gross secondary productivity and net secondary productivity in stick insects

The following table (Table 2.2) contains data collected from an experiment using a stick insect:

	Start of experiment	End of experiment
Mass of leaves (g)	29.2	26.3
Mass of stick insect (g)	8.9	9.2
Mass of faeces (g)	0.0	0.5

Table 2.2 Data from energetics experiment using a stick insect

A total of 10 stick insects were used. They were fed privet leaves.

The experiment lasted 5 days.

I will calculate net secondary productivity (NSP), respiration (R), and gross secondary productivity (GSP) from the data.

Calculating NSP

NSP can be calculated by measuring the increase in biomass in stick insects over a specific period of time. The increase in biomass in stick insects (NSP) is equal to the mass of food eaten minus biomass lost through respiration and faeces.

In this experiment:

NSP = mass of stick insects at end of experiment – mass of stick insects at start of experiment

Over a 5-day period:

$$\text{NSP} = 9.2\,\text{g} - 8.9\,\text{g} = 0.3\,\text{g}$$

Therefore:

$$\text{NSP} = \frac{0.3\,\text{g}}{5\,\text{g}} = 0.06\,\text{g per day}$$

Calculating GSP

GSP can be calculated using the following equation:

GSP = food eaten – faecal loss

Food eaten = mass of leaves at start of the experiment – mass of leaves at end of the experiment

$$\text{Food eaten} = 29.2\,\text{g} - 26.3\,\text{g} = 2.9\,\text{g}$$

$$\text{Faecal loss} = \text{mass of faeces at end of experiment} = 0.5\,\text{g}$$

Therefore, over a 5-day period:

$$\text{GSP} = 2.9\,\text{g} - 0.5\,\text{g} = 2.4\,\text{g}$$

Therefore:

$$\text{GSP} = \frac{2.4\,\text{g}}{5\,\text{g}} = 0.48\,\text{g per day}$$

GSP represents the mass of food absorbed by the consumer.

Calculating respiration

Respiration can be calculated from the equation:

$$\text{NSP} = \text{GSP} - \text{R}$$

where R = respiratory loss.

The equation can be rearranged to calculate R:

$$\text{R} = \text{GSP} - \text{NSP}$$

Therefore:

$$\text{R} = 0.48\,\text{g} - 0.06\,\text{g} = 0.42\,\text{g per day}$$

Estimating tree carbon stores in contrasting ecosystems

The carbon stored in tree trunks can be estimated for different forest types. For this, the circumference and height of trees must be estimated.

1 The circumference of a tree is measured at chest height (approximately 1.5 m above the ground). Tree trunk radius must be greater than 25 cm (or circumference must be greater than 157 cm) – smaller trees should not be measured.

2 Using a tape measure and clinometer, measure the height of the tree:

- Walk away from the base of the tree until the top of the tree is visible.
- Use a clinometer to measure the angle of elevation from a horizontal plane to the top of the tree (Figures 2.21 and 2.22).
- Use a tape measure to record the distance from the tree trunk to where the clinometer reading was taken.
- Record the height of the person taking the clinometer reading.
- Record all distance measurements in metres.
- Calculate the height of the tree using the following formula:

Tree height = distance along ground × tan(angle of elevation) + height of observer

3 Calculate the approximate volume of the trunk using the following formulas:

$$\text{Radius of tree } (r) = \frac{\text{circumference}}{2 \times \pi}$$

$$\text{Volume of trunk} = \pi r \times \frac{\text{height}}{3}$$

These calculations make the assumption that that the tree trunk is a cone.

4 Then calculate the biomass of the tree trunk using the formula:

Biomass = volume × nominal specific gravity

For broadleaved trees, nominal specific gravity = 0.53

For conifers, nominal specific gravity = 0.39

Precise figures for nominal specific gravity can be found on page 51 of the following publication: **https://www.forestry.gov.uk/pdf/WCC_CarbonAssessmentProtocol_V2.0_March2018.pdf/**

5 Calculate the carbon content of the trunk:

$$\text{Carbon content of trunk} = \frac{\text{biomass of trunk}}{2}$$

Ideally a large number of trees (approximately 25–50) should be sampled to get an estimate of the carbon content per unit area of forest. Trees can be selected using random numbers to generate *x* and *y* coordinates, with the tree nearest to the coordinate being measured.

Note: this method does not measure the total biomass of the trees, as canopy and root biomass are not estimated. For methods to estimate the total tree biomass, see **https://www.forestresearch.gov.uk/documents/2786/Revised-biomass-equations-27Jan2014.pdf**

Figure 2.21 A clinometer measures the angle from the top of an object to the horizontal plane. Trigonometry is then used to calculate the height of tall objects from the angle measured

Figure 2.22 Using a clinometer to measure the angle of elevation from a horizontal plane to the top of the tree

Ideas for investigations

Investigation on the extent to which an altered landscape affects carbon sequestration

Afforestation is used to mitigate the effects of climate change. But to what extent does the planting of new trees increase the uptake of carbon dioxide in the form of carbon? Measuring the carbon storage of a new forest can give an indication of the role of trees in reducing carbon dioxide concentrations in the atmosphere.

Choose an area of forest that is newly planted, a plantation, or alternatively a local woodland that has new growth within it.

Using the techniques outlined on page 39, estimate the carbon storage in tree trunks within your sample area.

Now you need to estimate the biomass of the canopy (the upper layer of a forest, containing the leaves of a tree) and the root ball (below-ground root mass). These can be estimated using the radius of the tree trunk and the specific data relating to the species of tree. This method is based on the analysis used by Forest Research: **https://www.forestry.gov.uk/pdf/Revised-biomass-equations-27Jan2014.pdf**

1 Record the radius and double it to determine the tree's diameter at breast height (DBH), expressed in centimetres.

If DBH is 7–50 cm then crown biomass = $a \times \text{DBH}^b$

If DBH >50 cm then crown biomass = $c + (d \times \text{DBH})$

where a, b c and d are species-specific constants shown in Table 2.3.

Species	*a*	*b*	*c*	*d*
Beech, Sycamore and Maple	0.000019	2.4767	−0.459519	0.015263
Cedar	0.000015	2.4767	−0.353198	0.011732
Corsican pine	0.000012	2.4767	−0.299529	0.009949
Douglas fir	0.000017	2.4767	−0.411768	0.013677
Grand fir	0.000015	2.4767	−0.353198	0.011732
Hemlock	0.000015	2.4767	−0.353198	0.011732
Larch	0.000044	2.0291	−0.129047	0.005039
Lodgepole pine	0.000018	2.4767	−0.430537	0.014300
Noble fir and other conifers	0.000015	2.4767	−0.353198	0.011732
Norwegian spruce	0.000015	2.4767	−0.353198	0.011732
Oak and all other broadleaved trees	0.000017	2.4767	−0.411551	0.013670
Scots pine	0.000016	2.4767	−0.394206	0.013094
Sitka spruce	0.000015	2.4767	−0.353198	0.011732

Table 2.3 Table for estimating tree crown biomass

- To estimate the biomass of the roots, further equations must be used. Again the equation used depends on the size of the tree.
- If DBH is 7–50 cm then root biomass = $e \times \text{DBH}^{2.5}$

  If DBH > 50 cm then root biomass = $f + (g \times \text{DBH})$

  where e f, and g are species-specific constants shown in Table 2.4.

Species	*e*	*f*	*g*
Beech, Sycamore and Maple	0.000023	−0.174882	0.009559
Cedar	0.000011	−0.082603	0.004515
Corsican pine	0.000011	−0.082603	0.004515
Douglas fir	0.000017	−0.133480	0.007296
Grand fir	0.000015	−0.118673	0.006487
Hemlock	0.000015	−0.118673	0.006487
Larch	0.000017	−0.133480	0.007296
Lodgepole pine	0.000017	−0.133480	0.007296
Noble fir	0.000011	−0.082603	0.004515
Norwegian spruce and other conifers	0.000012	−0.091547	0.005004
Oak and all other broadleaved trees	0.000023	−0.174882	0.009559
Scots pine	0.000015	−0.118673	0.006487
Sitka spruce	0.000021	−0.157579	0.008614

Table 2.4 Table for estimating root biomass

2 Now calculate the carbon content based on the biomass of the whole tree:

biomass of whole tree = trunk biomass + crown biomass + root biomass

3 To find the carbon content of the tree, divide the biomass of the whole tree by 2, that is:

$$\text{carbon content of tree} = \frac{\text{biomass of whole tree}}{2}$$

Ideally a large number of trees (approximately 25–50) should be sampled to get an estimate of carbon content per unit area of forest. Trees can be selected using random numbers to generate *x* and *y* coordinates, with the tree nearest to the coordinate being measured.

If carbon sequestration were to be the focus of an IA, the carbon content of different forest types could be compared, for example:

- forests containing native versus non-native species of tree
- forests where trees have been harvested for timbers versus undisturbed, pristine forest
- coppiced versus non-coppiced areas. Coppicing is a management practice where trees are cut off at ground level; this causes many rods, rather than one large trunk, to grow from the stump. It is used in, for example, temperate deciduous woodland and to open up the canopy and stimulate growth in the understorey, increasing the diversity of plants and animals.

ENVIRONMENTAL ISSUE

The effect of non-native species on forest carbon sequestration.

Measuring changes along an environmental gradient

Ecological gradients are found where two ecosystems meet or where an ecosystem ends. Abiotic and biotic factors change along the same ecological gradient.

Transects are used to measure changes along the gradient, to ensure that all parts of the gradient are measured (Figure 2.23):

- 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 1.0 m is sampled along the gradient.

Quadrats can be used to sample at regular intervals along a transect (see page 32):

- **Frame quadrats** are empty frames of known area (for example, 1 m^2).
- **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 2.11 on page 32 and Figure 2.24, right). 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 (that is, if a species touched 7 out of the 10 pins it has 70% frequency).

Figure 2.23 Sampling along an environmental gradient. A tape measure is laid out at 90° to the sea and abiotic and biotic factors are measured at regular intervals along it. The photo shows the site near the end of the succession which starts on a shingle ridge and ends in shrub communities

Figure 2.24 A point quadrat being used to measure plant species richness along a transect

ACTIVITIES

7 Distinguish between using a transect and a quadrat in collecting ecological field data.

8 An investigation was carried out on the effect of pesticide treatment on earthworm populations. The results are shown in the table:

Quadrats on soil treated with pesticide		Quadrats on untreated soil	
Earthworms per quadrat	**Frequency**	**Earthworms per quadrat**	**Frequency**
0	0	7	0
1	1	8	2
2	3	9	3
3	4	10	6
4	6	11	12
5	10	12	9
6	9	13	6
7	5	14	4
8	4	15	2
9	3	16	1
10	0	17	0

Table 2.5

a Plot a histogram of frequency against numbers of earthworms per quadrat.

b Describe the effect of pesticides on earthworm populations and suggest a reason for the observed results.

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 (for example, 0.6 m) vertically up the transect (Figure 2.25).
- 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.

ACTIVITIES

9 State what is meant by the term 'ecological gradient'.

10 Outline how you would measure changes in abiotic factors along an environmental gradient.

11 Describe **three** different methods for recording biotic factors along a belt transect.

12 Describe how you would collect data to show zonation in an ecosystem.

Planning ecological investigations

Ecology is the study of the interaction between organisms and their environment. In any given ecosystem, there are numerous complex, interconnected relationships. It is important in an ecological investigation to have a clear idea about the organisms that will be the focus of the investigation, and the relationship that is to be studied. You have to be careful that your investigation does not get too wide in scope, and has clearly defined parameters. Initial ideas about possible investigations can be gained from visiting a local nature reserve, woodland or other ecosystem. You may notice, for example, that certain species are only found in particular areas. You could test various abiotic factors, such as pH, light intensity, soil moisture and so on, to explore the reason for such patchy distribution, as well as sampling other species to see if there are any

Key definition

Zonation – 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.

Figure 2.25 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

Expert tip

Studying both biotic and abiotic factors allows general research questions such as *how do abiotic factors affect the distribution of organisms in ecosystems?* The research question can then be focused on a specific ecosystem. 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 organisms of an ecosystem and abiotic to the non-living parts.

biotic interactions. Based on initial studies, you then need to choose one specific independent variable to investigate, and one dependent variable, such as the effect of soil moisture on the distribution of one species. Other confounding variables, which might have an effect on the dependent variable, but which cannot be controlled, must be monitored (for example, light intensity, humidity and temperature).

Ecological investigations draw on the range of techniques and skills you have learned in this chapter, such as the use of:

- quadrats
- transects
- keys to identify organisms
- abiotic sampling techniques
- biotic sampling techniques
- laboratory skills, for example, soil moisture determination
- diversity indices (see pages 44–48, next chapter).

The sampling methodology will be central to your investigation. Will you carry out random sampling (appropriate if your study area is homogeneous) or sample along a line transect (suitable where there is an environmental gradient and a change in species composition)?

Statistical tests are usually used in ecology to investigate whether observed results are significant or not (that is, whether they are due to chance, or show that there is a real link between independent and dependent variables and therefore a causal relationship). It is important to select the appropriate test for your investigation. The use of statistical tests in ecological investigations is covered in Chapter 9.

ENVIRONMENTAL ISSUES

- The effect of increased human population size on ecosystems, through increased visitor numbers.
- The effect of human disturbance on abiotic and biotic factors.
- The effect of eutrophication on aquatic invertebrates.
- The effect of acid rain on plant growth.
- The effect of air pollution on biotic components of the ecosystem.

Ideas for investigations

Possible ecological investigations are almost limitless, but here are a few suggestions:

- Determine whether there is a correlation between the distribution of a plant species and an abiotic factor, such as light intensity. Does human activity, such as trampling of vegetation, affect species distribution?
- Explore whether there is an association between plant species, or between a plant species and an animal. For example, thyme (*Thymus serpyllum*) is often observed growing on anthills. Is this relationship affected by human activities?
- Rocky shores provide many opportunities for investigations:
  - Whether there is a correlation between height and width of molluscs, for example, limpets (*Patella vulgata*), and exposure to wave action. Sheltered and exposed shorelines could be studied. What effect could increased wave action, as a result of climate change, have on mollusc populations?
  - Crabs make good subjects for ecological investigations, for example, fiddler crabs (*Uca* spp), ghost crabs (*Ocypode* spp.) and soldier crabs (*Mictyris* spp.). They play an important role in the nutrient cycling and energy flow of coastal ecosystems, and can be used as indicators of ecosystem disturbances. See: **http://ecolabnie.wixsite.com/shirley/research**
- Acid rain has an adverse effect on aquatic plants. The effect of acidity on plant growth could be studied.
- Lichens (a symbiotic association between fungal and algal species) are sensitive to air pollution, specifically sulphur dioxide. The abundance and distribution of lichens in industrial and rural areas could be studied and compared.

3 Biodiversity and conservation

Terminology

Biodiversity is a broad concept encompassing the total diversity of living systems, which includes **species diversity**, **habitat diversity** and **genetic diversity**.

Conservation efforts rely on the quantification of biodiversity to provide an understanding of natural systems and the effect of human activities on them.

ENVIRONMENTAL ISSUE

Central to conservation is the concept of **sustainability**. Sustainable development is defined as 'development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.' This is something that conservation aims to achieve, as well as preserving life that currently exists on Earth.

The difference between richness and diversity

Species diversity in communities is a product of two variables: the number of species (**richness**) and their **relative abundance** (**evenness**). Species richness in an area can be high, but diversity low (Figure 3.1). A community with high evenness is one that has a similar abundance of all species – this implies a complex ecosystem where there are many different niches that support a wide range of different species. In contrast, low evenness refers to a community where one or several species dominate – this suggests lower complexity and a smaller number of potential niches, where a few species can dominate.

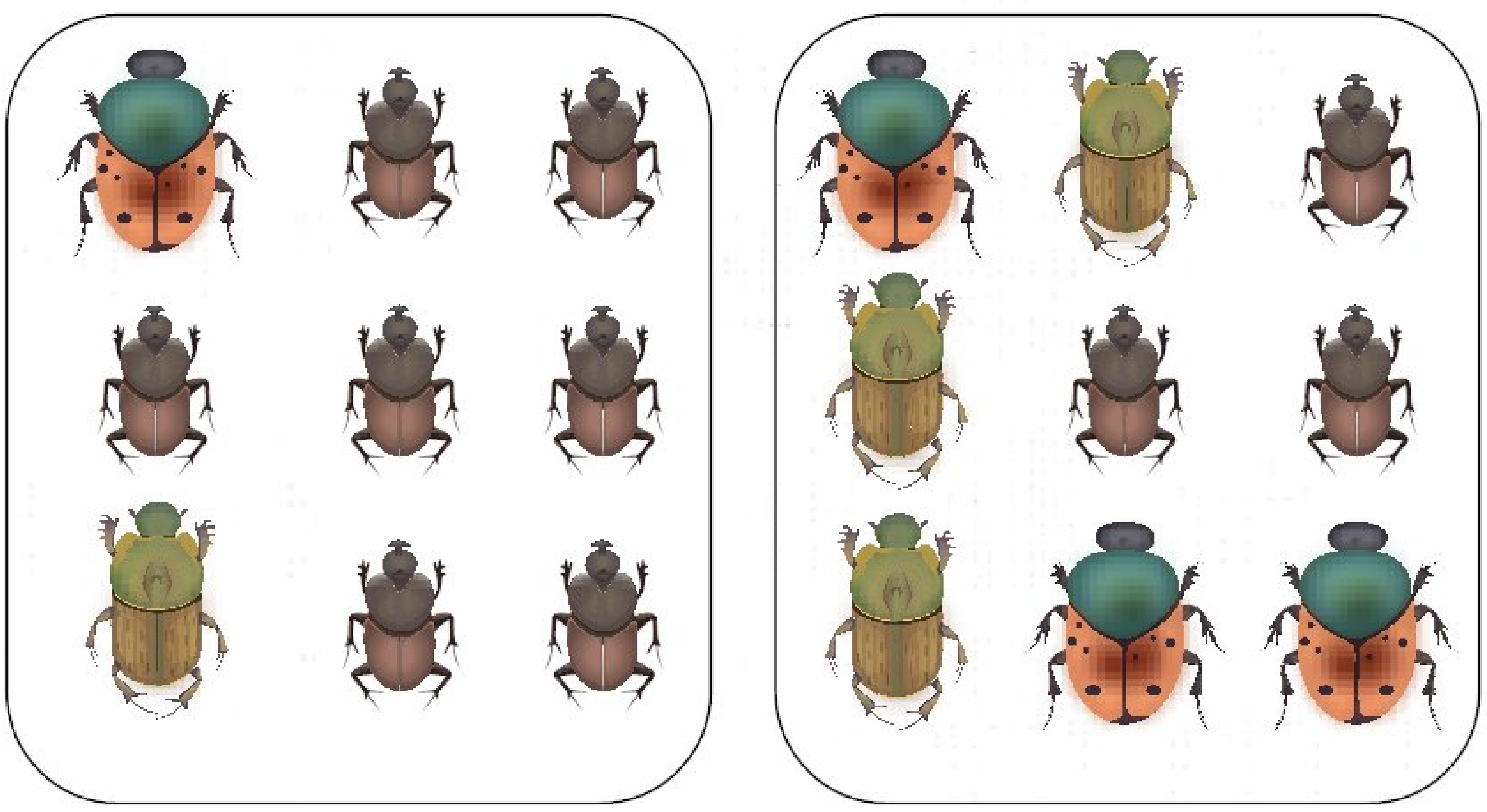


Figure 3.1 Species richness versus species diversity. The species richness is the same in both ecosystems (ecosystem A and ecosystem B – three species of beetle in each). In ecosystem B, diversity is higher than ecosystem A because the evenness is higher. One species dominates in ecosystem A, indicating a less complex ecosystem

Species diversity can be calculated using diversity indices, such as the **Simpson's diversity index**, which uses the equation:

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

where

D = diversity index

N = total number of organisms of all species found

n = number of individuals of a particular species

$\sum$ = the sum of

Key definitions

Biodiversity – the amount of biological or living diversity per unit area. It includes the concepts of species diversity, habitat diversity and genetic diversity.

Species diversity – the variety of species per unit area. This includes both the number of species present and their relative abundance.

Habitat diversity – the range of different habitats in an ecosystem or biome. Conservation of habitat diversity usually leads to the conservation of species and genetic diversity.

Genetic diversity – the range of genetic material present in a population of a species.

Conservation – works to protect and preserve the Earth's ecosystems, so that future generations can live in a world that has the same biological richness we enjoy today.

Sustainability – using the resources of the Earth in a way that does not adversely affect future generations.

Species richness – the number of species in a community.

Relative abundance – the relative number or amount of one species compared to the other species in a community.

Evenness – the proximity of the numbers of each species in a community. High evenness indicates all species are similar in abundance, and low evenness indicates that one or several species dominate an environment.

Diversity index values are relative to each other and are not absolute, unlike measures of, for example, temperature, which are on a fixed scale. This means that two different areas can be compared to each other using the index, but a value on its own is not useful.

Other important points about the Simpson's diversity index:

- 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, for example, logging, pollution, recent colonisation or agricultural management, where one species may dominate.

Biological diversity can be quantified in many different ways. The two main factors taken into account when measuring diversity are richness and evenness. Richness is a measure of the number of different kinds of organisms present in a particular area. For example, species richness is the number of different species present. However, diversity depends not only on richness, but also on evenness. Evenness compares the similarity of the population size of each of the species present.

The number of species per sample is a measure of richness. The more species present in a sample, the 'richer' the sample. Species richness as a measure on its own takes no account of the number of individuals of each species present. It gives as much weight to those species which have very few individuals as to those which have many individuals. Evenness is a measure of the relative abundance of the different species making up the richness of an area. As species richness and evenness increase, so diversity increases. The Simpson's diversity index is a measure of diversity which takes into account both richness and evenness.

Expert tip

Make sure you use the Simpson's diversity index formula shown on page 44 (that is, the one from the ESS subject guide). There are other versions of the index that lead to different calculations.

ENVIRONMENTAL ISSUE

The impact of human activities on biodiversity, for example:

- how habitat disturbance affects diversity
- how changes in abiotic factors due to human activities (for example, deforestation) impacts biotic factors (for example, species diversity)
- the introduction of exotic/non-native species and the effect on biodiversity.

Worked example

Analysis of the biodiversity of two communities using the Simpson's diversity index

Table 3.1 (below) contains data from two different habitats: one undisturbed forest (pristine forest) and the other forest that has had trees removed from it (logged forest).

Species	Numbers found in pristine forest	Numbers found in logged forest
Species # 1	13	2
Species # 2	13	7
Species # 3	13	39
Species # 4	13	4
Species # 5	13	5
Species # 6	13	21
Number of species	6	6
Total number of individuals	78	78

Table 3.1 The number of species and their abundance in two habitats

The species richness (number of species present) and the number of individuals in each forest are the same. The distribution of species in the pristine forest is, however, more even than the logged forest, that is, the evenness is higher in the undisturbed forest.

The Simpson's diversity index can be calculated for each habitat. This can be done using a table to calculate components of the index (Table 3.2). For each species, $n(n-1)$ is calculated (the number of individuals in a species multiplied by this number minus 1). The values of $n(n-1)$ for each species are then added together (Σ is a symbol for the Greek letter sigma, meaning 'sum of').

Species	Number (n) found in pristine forest	$n(n-1)$	Number (n) found in logged forest	$n(n-1)$
Species # 1	13	13(12) = 156	2	2(1) = 2
Species # 2	13	13(12) = 156	7	7(6) = 42
Species # 3	13	13(12) = 156	39	39(38) = 1482
Species # 4	13	13(12) = 156	4	4(3) = 12
Species # 5	13	13(12) = 156	5	5(4) = 20
Species # 6	13	13(12) = 156	21	21(20) = 420
	$\Sigma n(n-1) =$	936	$\Sigma n(n-1) =$	1978

Table 3.2 Calculating the Simpson's diversity index for two habitats

The final stage of the calculation involves dividing $N(N-1)$, where N is the total number of individuals of all species, by $\Sigma n(n-1)$. In this example, $N(N-1)$ for each habitat is 78(77) = 6006.

Species diversity, as measured by the Simpson's diversity index, for each habitat:

Pristine forest:

$$D = \frac{6006}{936} = \mathbf{6.42}$$

Logged forest:

$$D = \frac{6006}{1978} = \mathbf{3.04}$$

What do these values imply about each habitat?

- There is greater 'evenness' between species in pristine forest. This implies more opportunity for niches in this habitat, due to greater resources and space, leading to greater diversity.
- There is less competition due to non-overlapping niches in pristine forest.
- One species does not dominate in undisturbed forest, reflecting greater habitat complexity.
- Logged forest is a less complex habitat with fewer, or overlapping, niches. One species can dominate, leading to lower diversity.

■ ACTIVITIES

1 Calculate the Simpson's diversity index for habitat B using data from Table 3.3 below.

	Number of individuals found in each habitat				
Species found	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

Table 3.3 Comparing the species diversity of five habitats

2 Describe and explain the differences between the habitats shown in the table.

3 Suggest reasons for the different values of the Simpson's diversity index recorded in the different habitats.

Plant diversity

To calculate species diversity, both the number of individuals in a sample and the number of species (the species richness) must be known. While animal abundance can be simply recorded by counting the number of individuals in a sample, estimating the amount of each plant species in a given area can be more difficult. Plant abundance for use in, for example, the Simpson's diversity index, can be obtained in a number of different ways:

- Stem counts can be taken (that is, the number of plant stems of a particular species in a specific area). This can be time-consuming for species with lots of stems. In addition, some species form colonies or can spread from one plant, leading to multiple stems from what is essentially the same organism. Plants also vary in size – some have large stems and others much smaller – and so stem count does not account for variations in biomass. Plant stem counts must be therefore used when colonies of plants are not present and all plants are of approximately equivalent size.
- Density: the number of plants per unit area. Usually this measurement is used for studying trees and plants that can be clearly recognized as individuals. Relative density is calculated by dividing the number of individuals of a species by the total number of individuals present in the sample and multiplying by 100.
- Percentage cover can be used to determine the relative abundance of plants. This estimates the relative amount of space each species occupies in a specific area (see Chapter 2 page 31). Estimates can vary according to the ways in which individuals carry out the measurement – that is, they are subjective. The advantage of this method is that it offers a relatively fast and comparative measure of species abundance.
- Classes can be attributed to different percentage cover estimates. Even though the estimates of percentage cover are subjective, people tend to agree as to which class a measurement should be assigned. Most investigators will choose the same percentage cover class when looking at the same sample plot, and so it is a more reliable and accurate measure of relative plant abundance. There are several different ways of attributing classes (Table 3.4). The cover classes, rather than the measurements of percentage cover, are used in diversity indices.

Percentage cover class	Percentage cover (%)
1	<5
2	5–25
3	25–50
4	50–75
5	75–100

Table 3.4 Attributing scales to percentage cover classes

There are a variety of different cover scales that can be used, some of which use description of plant cover as well as estimates of percentage cover (for example, the Braun-Blanquet, Domin, Krajina, Carolina and one used in New Zealand vegetation surveys – Table 3.5).

Range of cover	Description	Scale				
		Braun-Blanquet	Domin	Krajina	Carolina	New Zealand
Single individual	Solitary with small cover	1	1	1	1	1
Sporadic or few	Few individuals, with small cover	1	1	1	1	1
0–1%		1	2	1	2	1
1–2%	1	1	3	1	3	2
2–3%	1	1	3	1	4	2
3–5%	1	1	4	1	4	2
5–10%	Any number of individuals, with 5–25% cover	2	4	4	5	3
10–25%	2	2	5	5	6	3
25–33%	Any number of individuals, with 25–50% cover	3	6	6	7	4
33–50%	3	3	7	7	7	4
50–75%	Any number of individuals, with 50–75% cover	4	8	8	8	5
75–90%	Any number of individuals, with cover >75% of sample area	5	9	9	9	6
90–95%	5	5	10	9	9	6
95–100%	5	5	10	10	10	6

Table 3.5 Comparison of five different scales used to record relative percentage vegetation cover

Scales with a large number of classes may be more appropriate for diversity measurement, because they give a greater range or relative abundance.

Indicator species

Changes to **indicator species** may show the effects of disturbance to an ecosystem. These species are ones whose presence, absence or abundance can be used as an indication of pollution or other habitat disturbance.

Different species have different levels of tolerance to environmental conditions, which means that if change occurs to a habitat, some species can survive and others cannot. The presence or absence of these indicator species can be used to 'signpost' altering conditions in the environment. Indicator species can be used, for example, as an indirect measure of pollution, or to indicate environmental degradation due to habitat disturbance. Examples of indicator species include:

- Nettles (*Ullica dioica*) indicate high phosphate levels in the soil.
- The red alga (*Corauina officinalis*) inhabit saline rock pools and are absent from brackish pools.
- Certain lichen species (such as *Usnea alliculata*) indicate very low levels of sulphur dioxide in the atmosphere (see below and also Chapter 6, pages 94–95, 97).

Lichens are dual organisms; their body (called a thallus) is made of a fungal component and an algal or photosynthetic bacterium (cyanobacterium) component living together for mutual benefit (Figure 3.2). There are several thousand different species of lichen, often occurring in quite hostile habitats. Compact fungal hyphae make up the bulk of the lichen, and this component absorbs and retains water and minerals. The algal or cyanobacterial component carries out photosynthesis.

Lichens are especially susceptible to airborne pollutants dissolved in rain water (Chapter 6, page 94) because their surfaces are not protected by a waxy cuticle. The lichen thallus absorbs and accumulates various pollutants, and samples of lichens may be analysed for contamination by heavy-metal ions. The effects of pollution on the extent of their growth may also be a valuable indicator.

Key definition

Indicator species – an organism used to assess a specific environmental condition.

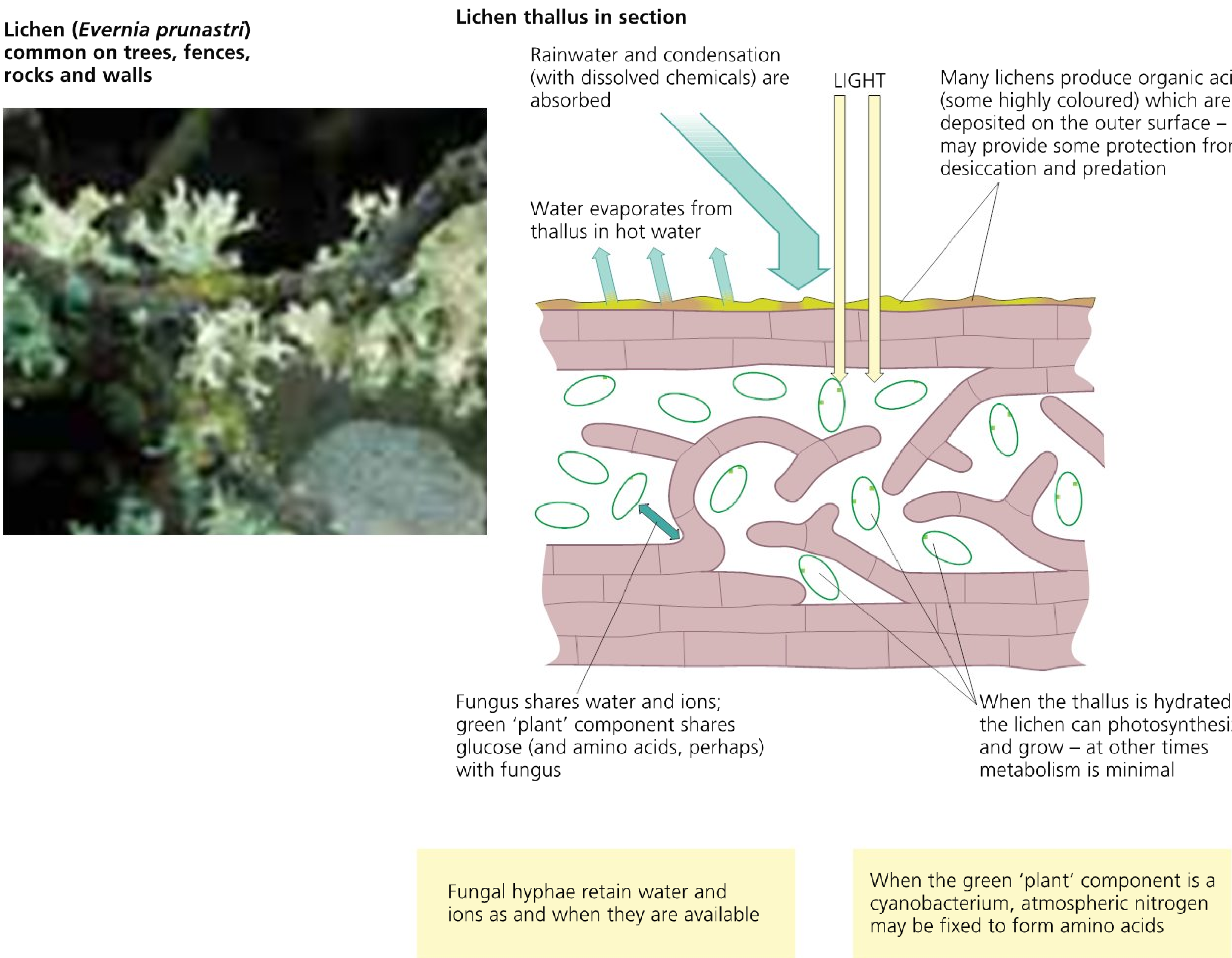


Figure 3.2 The physiology of lichen mutualism

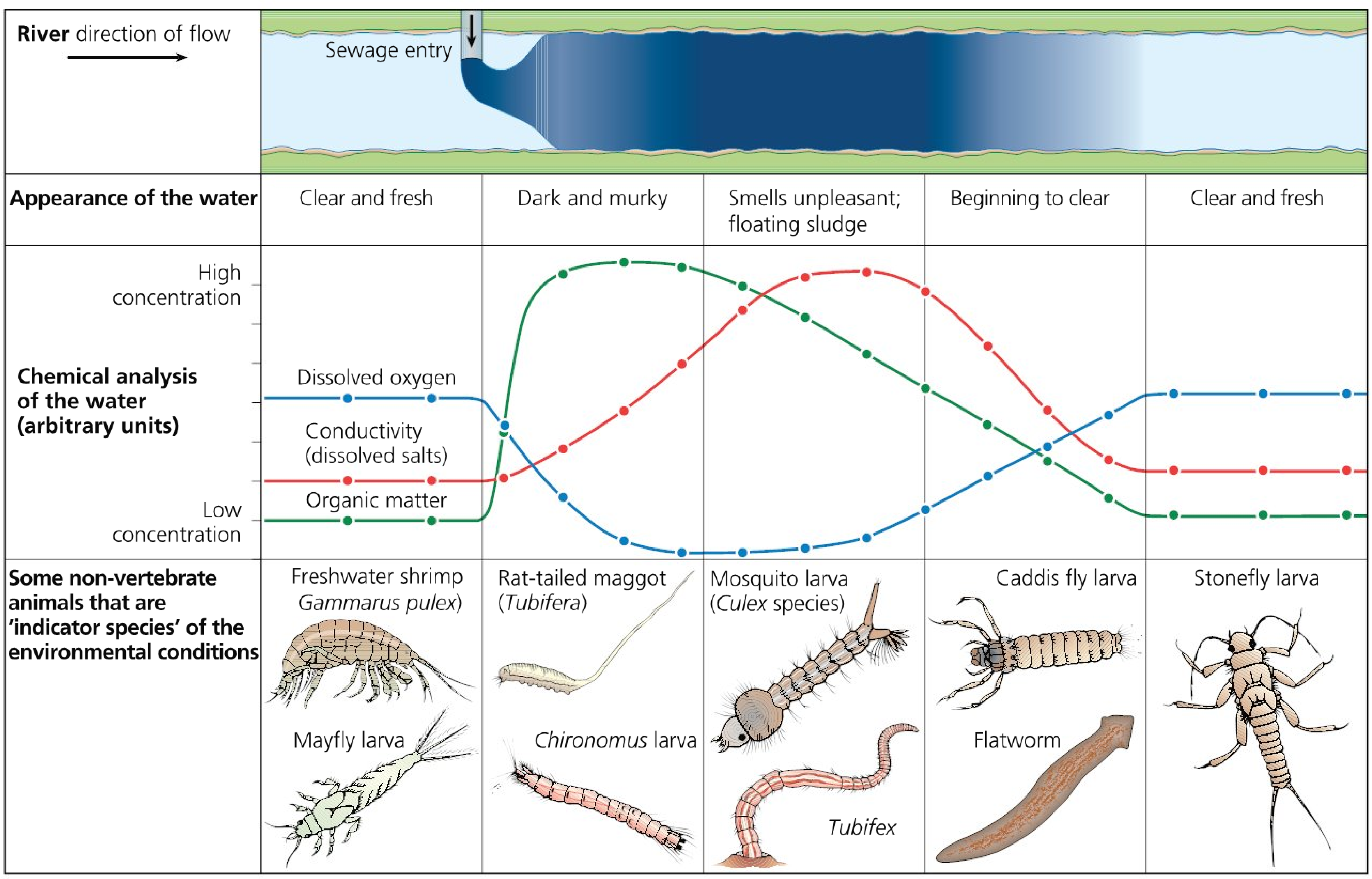


Figure 3.3 The effect of pollution of a river with untreated sewage can be observed by eye, measured by chemical analysis, and analysed using indicator species

Freshwater invertebrates such as *Tubifex* worms, bloodworms and mayfly nymphs can also be used as indicators (Figure 3.3 on page 49).

Relative numbers of indicator species can be used to calculate the value of a biotic index. Once such index, the Trent biotic index (see Chapter 4, pages 60–61), was first created and published by Frank Woodiwiss in 1964. The index indicates the quality of freshwater streams and rivers and is based on the disappearance of certain indicator species as levels of pollution increase. It uses the presence or absence of six key organisms (stonefly larvae, mayfly larvae, caddis fly larvae, *Gammarus* shrimp, *Asellus aquaticus* (or water hoglouse), *Tubifex* worms and/or non-biting midge larvae) to indicate the relative level of pollution in fresh water.

The larvae feed and live in the river prior to metamorphosis into adult flying insects, while *Asellus aquaticus* is a freshwater crustacean resembling a woodlouse. Changes in the light intensity and concentration of dissolved oxygen cause less-tolerant species to die out (Figure 3.3 on page 49). Certain species are tolerant of organic pollution and the low oxygen levels associated with it. They are found in high-population densities where an organic pollution incident occurs. Other species cannot tolerate low oxygen levels and, if organic pollution enters the river where they live, they move away or do not survive. As pollution increases, diversity decreases.

The Trent biotic index uses the presence or absence of these indicator species to provide a score of one to ten, where the values correspond to one of four basic categories describing water quality: excellent, good, fair or poor. A score of 10 is considered to be clean water.

ENVIRONMENTAL ISSUE

The effects of atmospheric, land or water pollution on biodiversity.

Conservation

In situ conservation

***In situ* conservation** is the conservation of species in their natural habitat. This means that endangered species, for example, are conserved in their native habitat. Not only are the endangered animals protected but also the habitat and ecosystem in which they live, leading to the preservation of many other species. *In situ* conservation works within the boundaries of conservation areas or nature reserves.

Key definition

***In situ* conservation** – the conservation of species in their natural habitat.

In situ conservation may require active management of nature reserves or national parks. This may mean active clearing of overgrowth, limiting predators, controlling poaching, controlling access, reintroducing species that have become locally extinct and removing alien species. In addition to such measures, successful protected areas also have the following characteristics:

- They provide a vital habitat for indigenous species; this can include habitat and food for migrating species such as birds.
- They create community support for the area.
- They receive adequate funding and resources.
- They carry out relevant ecological research and monitoring.
- They play an important role in education.
- They are protected by legislation.
- They have policing and guarding policies.
- They give the site economic value due to ecotourism.

The effect of biogeographic factors

Biogeographic factors affect species diversity and so must be taken into account when planning nature reserves.

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 3.4).

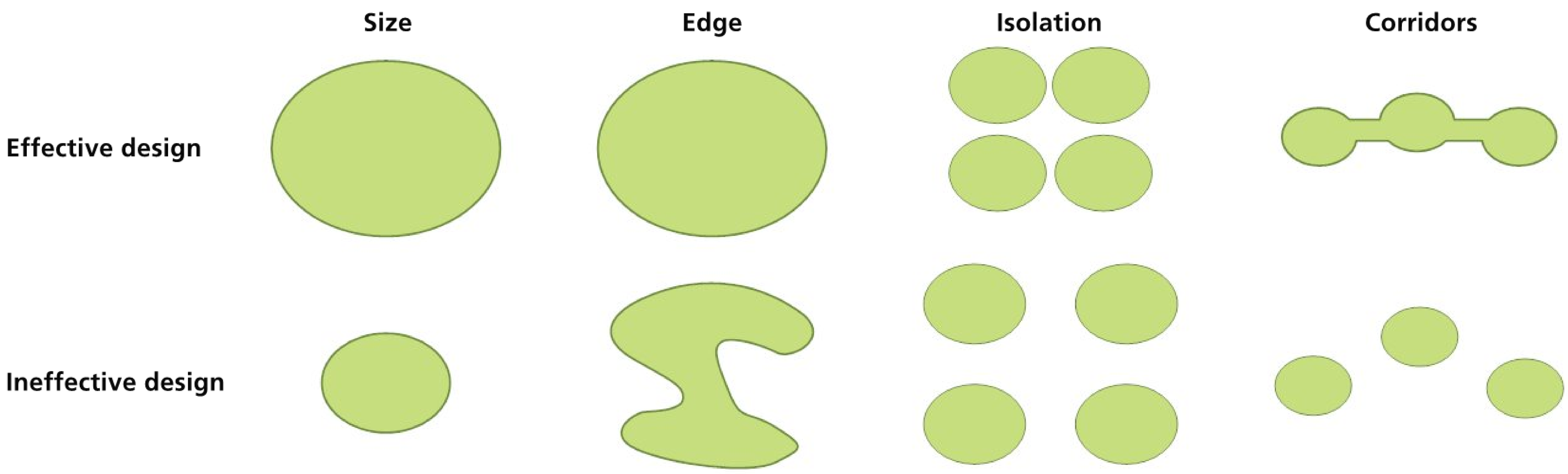


Figure 3.4 Features of effective reserve design

Nature reserves that are better for conservation have the following features:

- They are large, so that they:
  - support a greater range of habitats, and therefore greater species diversity
  - have higher population numbers of each species
  - have greater productivity at each trophic level, leading to longer food chains and greater stability
  - maintain top carnivores and large mammals.
- They have a low perimeter : area ratio to reduce edge effects (see below). Fewer edge effects mean more of the area is undisturbed. Edge conditions are very different to those of the interior habitat (hotter, less humid and windier) and so flora and fauna that are interior specialists cannot survive in edge conditions.
- The best shape for a reserve is a circle as this has the smallest edge area compared to interior area; it is better than an elongated strip of land or one that has an undulating edge, even if the total area is the same.
- They maintain gene flow between fragmented reserves (that is, reserves that have divided areas) by allowing movement of animals and plants along corridors.
- They have corridors to allow movement of large mammals and top carnivores between fragments.

Key definition

Edge effects – changes to abiotic conditions at the boundary where very different environments meet, and the corresponding effects on biotic factors (that is, the community).

Edge effects

Human disturbance can lead to the creation of habitat islands within areas of cleared land (Figure 3.4). Such habitat islands may form important nature reserves where surviving undisturbed ecosystems can be conserved. **Edge effects**, as well as island size, have an effect on diversity of these habitat islands (Figure 3.5).

- Edge effects exist at the boundary between two different habitats or ecosystems, for example, where forest and land cleared for agriculture meet.
- As the total area becomes smaller, the edge becomes proportionally larger.
- Larger islands have a smaller perimeter : area ratio than smaller islands, and so have fewer edge effects. In Figure 3.5:
  - Island A is larger than B or C and so has fewer edge effects.
  - Island B is larger than C, and so has a larger area of undisturbed forest than island C.

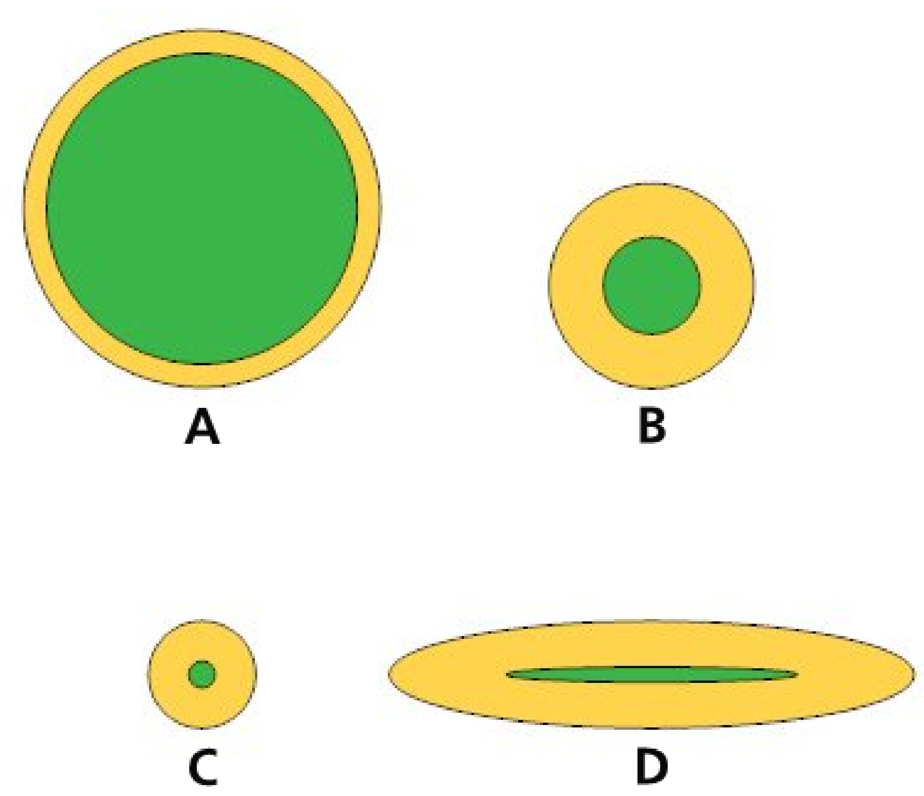


Figure 3.5 The edge effects on habitat islands of different sizes and shapes. Yellow areas indicate edge habitat; green areas indicate interior undisturbed habitat

- Island C is almost entirely edge habitat – this will have a very different species composition to undisturbed forest, with lower conservation value.

- The shape of the habitat area is important – elongated areas (island D) have a proportionally larger edge effect than rounder areas.
- The edge areas can benefit some species that enjoy edge conditions, although these may be species from outside the habitat island.
- Edge habitats will have a different species composition to interior forest.
- Edge effects should be minimized if the largest area of undisturbed habitat is to be conserved.
- Species richness may increase in edge habitat because it represents the intersection of different habitats where species from these habitats can mix, although species diversity can decrease due to decreased evenness.
- Fewer interior species will be found in edge habitat, and so edge habitat has lower conservation value.

Figure 3.6 shows how different variables associated with island biogeography theory correlate with species richness.

In each case, increasing island size increases species richness and also diversity.

Diversity increases because:

- The range and diversity of niches increases as forest area increases.
- The greater range of niches means that a larger number of species can co-exist.
- Both evenness and richness increase, leading to greater diversity.

ENVIRONMENTAL ISSUE

The impact of human disturbance and fragmentation of ecosystems due to increased edge effects on biodiversity.

ACTIVITY

4 Evaluate the particular challenges in the management of a nature reserve that is maintained near your home, school or college.

ENVIRONMENTAL ISSUE

Habitat reduction is linked to species richness and diversity. How does habitat size affect the numbers of species present and their relative abundance?

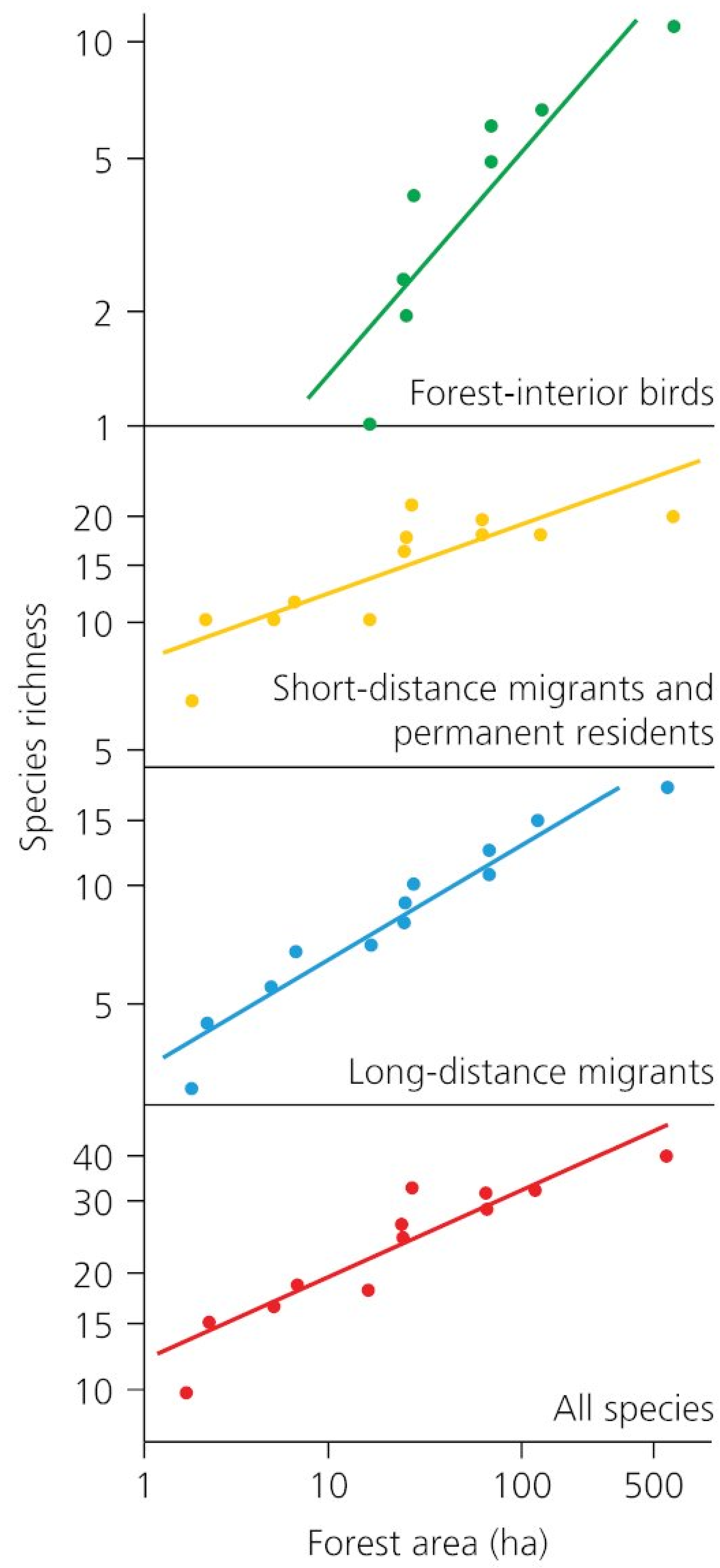


Figure 3.6 The effect of habitat area on species richness

Ideas for investigations

Using secondary data, comparisons could be made between areas of habitat that are undisturbed and those that have been affected by human actions. How has species richness been affected?

Size of area correlated to species richness is a central idea in conservation. Either using secondary data, or collecting your own primary data from an ecosystem near you which has been divided into different sized patches, you could investigate the effect of area size on species richness. Do different sized habitat patches have different measures of species richness? Has species diversity been affected?

Ex situ conservation

***Ex situ* conservation** is the preservation of species outside their natural habitats. This usually takes place in zoos, which carry out captive breeding and reintroduction programmes:

- 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.

Key definition

***Ex situ* conservation** – the preservation of species outside their natural habitats, for example, in zoos and wildlife parks.

Botanic gardens also have a role in *ex situ* conservation, where both living collections and seed banks are used to store genetic diversity.

Zoos have played an important role in maintaining population numbers of critically endangered animals and returning them to the wild (see Figure 3.7).

Captive breeding programmes in zoos (*ex situ* conservation) have increased numbers of golden lion tamarin monkey from a low of 400 in the 1970s to about 1 000 today. Captive breeding has been carried out at institutions such as Bristol Zoo in the UK. There are also efforts to preserve the native forests of the monkey in Brazil (*in situ* conservation), for example, at the Reserva Biologica de Poyo Antas, near Rio de Janeiro.

Figure 3.7 A golden lion tamarin monkey (*Leontopithecus rosalia*)

Ideas for investigations

Captive breeding can be used to sustain population numbers of endangered animals and be potentially used to reintroduce and restore wild populations of the species. Examine the case study of one species from a local zoo or wildlife park. See if there is secondary data focusing on the endangered animal. Has the breeding programme been successful? What data could you examine to see whether this is the case or not?

ENVIRONMENTAL ISSUE

How can species be protected and are these methods effective?

4 Water systems

The hydrological cycle

The hydrological cycle is the transfer of moisture between the atmosphere, the lithosphere and the biosphere. In simple terms, it includes all forms of precipitation, surface run-off, flow and evapotranspiration. Water is a precious resource and people have affected the hydrological cycle in a number of direct and indirect ways. One example is the human impact on vegetation. This can be observed in many schools and/or local parks.

Rainfall

To measure **rainfall**, place a number of rain gauges on an exposed flat roof (or some other exposed area). There will be some variability in the rainfall at each site, so calculate an average. To calculate the amount of **interception** produced by different types of plants, place a small number of rain gauges under different types of vegetation, for example, coniferous trees, deciduous trees and small shrubs. There will be important seasonal differences depending on the vegetation, and there will be variations in interception depending on the age of the vegetation.

Interception

Interception is measured by comparing the rainfall under different vegetation types with that of rainfall in a nearby open space, that is, without vegetation cover. Several rain gauges need to be placed in both areas (under each vegetation type and open space) and data can be collected for a number of days. Rainfall should be recorded at the same time each day, so that 24-hours' worth of rainfall is collected.

Key definitions

Rainfall – precipitation falling as a liquid. Precipitation encompasses all forms of moisture including rain, snow, dew and fog.

Interception – the capture and storage of water by vegetation.

Figure 4.1 Measuring rainfall

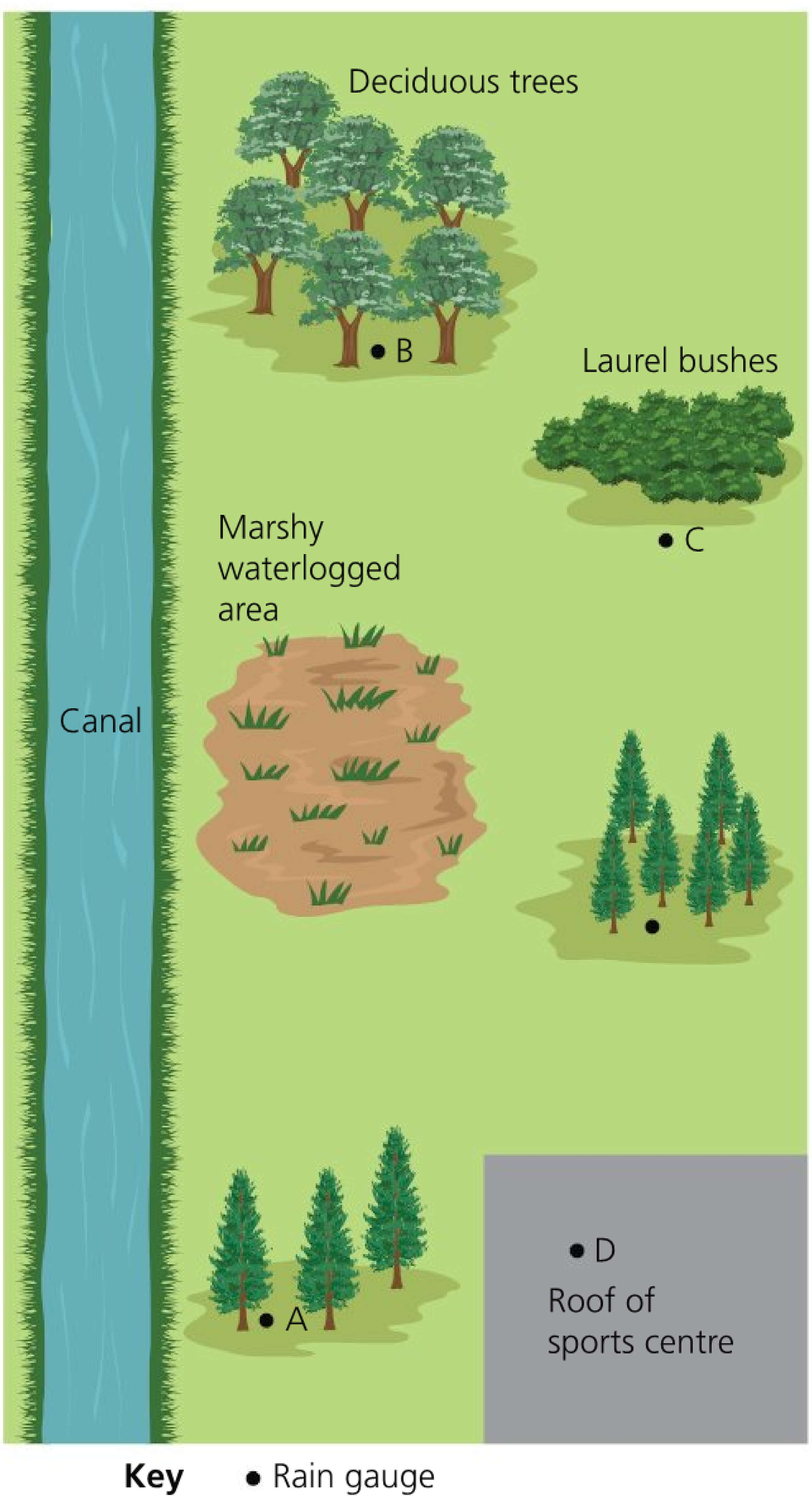


Figure 4.2 Location of rain gauges

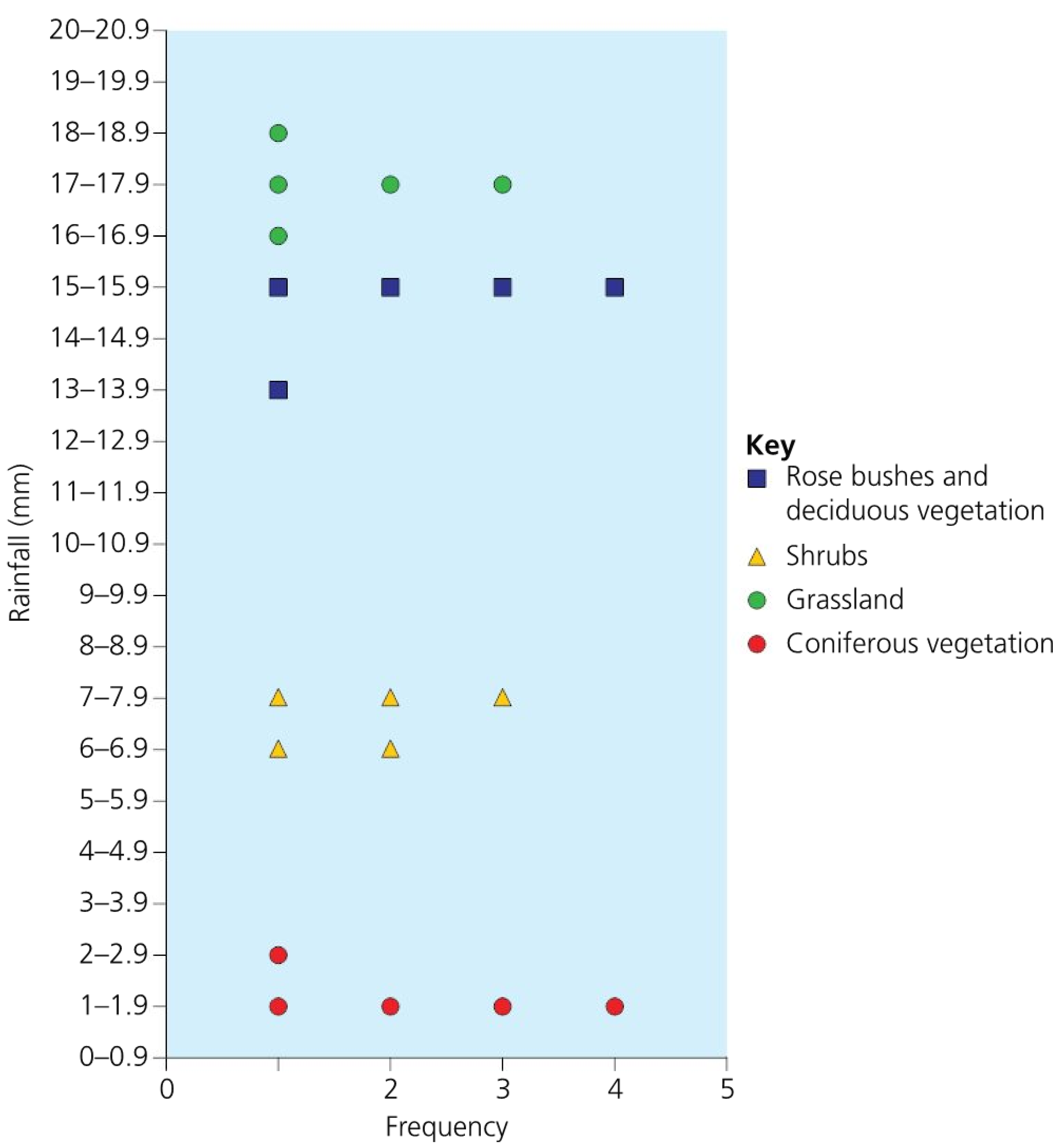


Figure 4.3 Dispersion diagram to show variation of rainfall totals in rain gauges under different types of vegetation

Another method is to place a line of rain gauges at increasing distance from a tree and to measure the amount of interception during a storm. Rainfall total could be measured every 15 or 30 minutes and it would be possible to see how interception varies during the storm. It might be expected that the amount of interception would be high at first, but as the amount of water stored by vegetation increases, the amount of interception will begin to decrease. A control gauge should be placed in the open area to record the amount of rainfall that is occurring in open ground.

Expert tip

When measuring the volume of liquid in a cylinder, such as a rain gauge, your eyes should be level with the top of the water column. Read the volume at the lowest level.

ACTIVITIES

Site	Environment	Rainfall (mm)
A	Coniferous woodland	1.0, 2.0, 1.5, 1.0
B	Deciduous woodland	15.0, 14.5, 16.0, 13.0
C	Evergreen bushes	7.0, 8.0, 9.0, 7.5
D	Exposed flat roof	17.0, 18.5, 17.0, 16.5
E	New conifer plantation	?

Table 4.1 Rainfall totals recorded at sites in Figure 4.2 (on page 54)

1 a Describe and account for the variation in rainfall at each site.
  b At what time of year do you think the survey was carried out? Justify your answer.
  c How and why do you think the results would differ between winter and summer? Justify your answer.
  d At site E, a new coniferous plantation has been established. How will that compare, hydrologically, with the mature coniferous forest at site A? Justify your answer.

Stemflow

Stemflow down a tree can be measured with the use of plastic tubing. The tubing will need to be split, so that the top half is missing, and the tube should extend around the tree. If a number of trees are being studied, the tubing should be placed at the same height on each tree. Any gap between the tubing and the tree should be sealed and made impermeable with a sealant. The lower end of the tubing should be directed into a collecting vessel, such as a jar, bucket or rain gauge.

Key definition

Stemflow – moisture that flows down the stem of a plant.

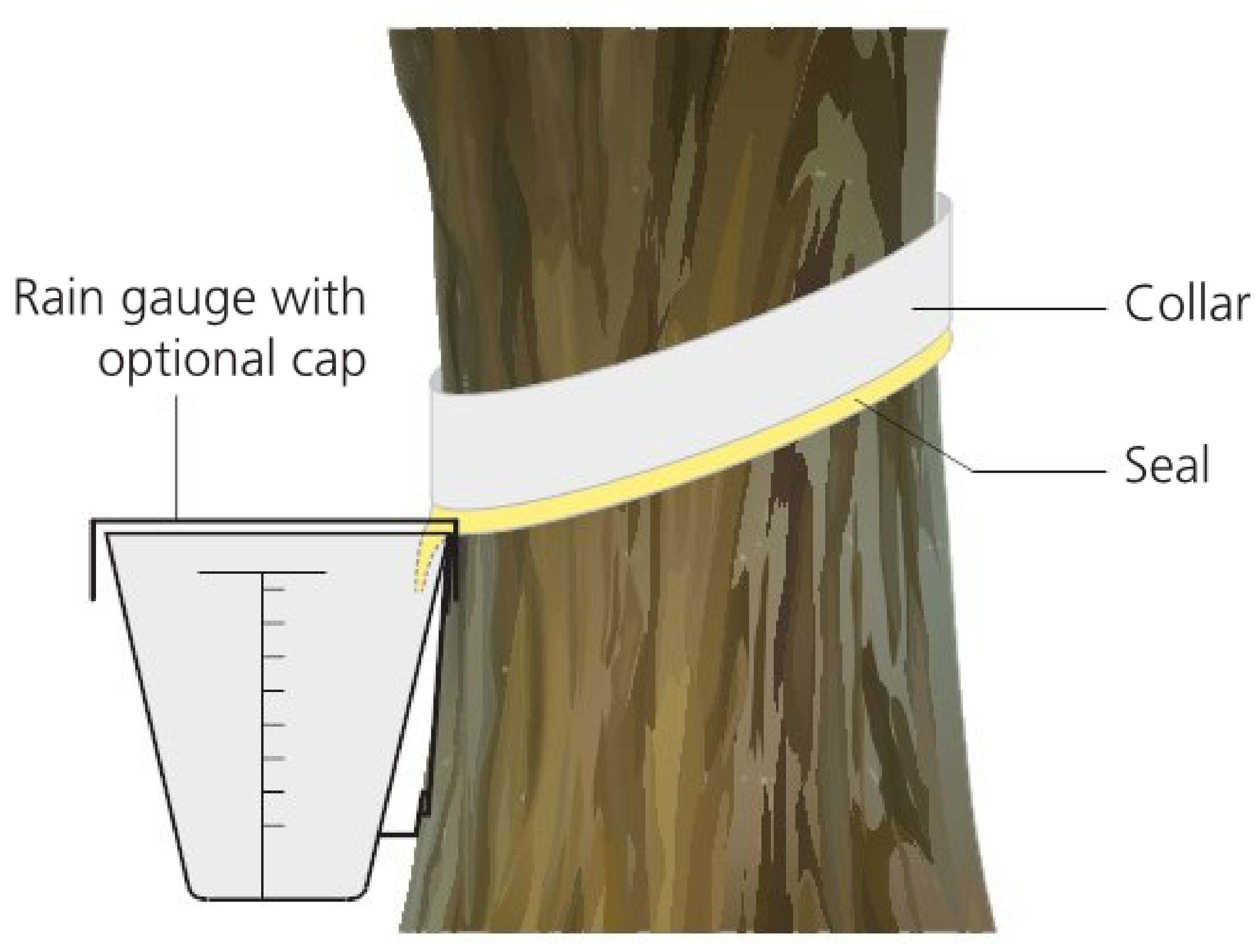


Figure 4.4 Measuring stemflow

Evaporation

Evaporation can be measured using an evaporation pan or an open tray/plastic container of water. If there is no rainfall, changes in the water level are likely to be caused by evaporation. To measure evaporation in different places, it is important to use recording trays/boxes of the same size and containing the same initial volume of water. Rainfall should also be recorded while measuring evaporation, since if it rains, the amount of water in the trays will increase.

Key definition

Evaporation – moisture loss from the ground and from water surfaces.

Infiltration

To measure **infiltration**, you will need a number of pieces of equipment. These include a container of water (such as an empty food tin), a metal or plastic tube or can, a 30-cm ruler, a stopwatch, a block of wood and a mallet (wooden hammer).

The tube or can needs to be inserted into the ground with the block of wood on top, using the mallet to hit it into the ground. This ensures that the pressure on the tube is evenly spread and that the tube stands vertically in the soil.

The infiltration tube is filled to a pre-arranged depth, for example, 15 cm. Using the stopwatch, record the level of the water at 30-second intervals. To keep the water pressure consistent, the water level should be topped up once the water has dropped to a certain level, for example, 7.5 cm. The time taken for the water level to drop to 7.5 cm should also be recorded.

Key definition

Infiltration – water seeping into the ground.

Figure 4.5 Measuring infiltration

ACTIVITIES

Time from pouring water into measuring cylinder (minutes)	Height of water in measuring cylinder at each measuring site (cm)			
	Flower garden	Sports field	Woodland	Floodplain
0	10.0	10.0	10.0	10.0
1	7.0	8.0	5.0	9.0
2	4.0	6.0	3.0	8.0
3	2.0	4.0	0.0	7.0
4	0.5	2.0		6.0
	0.0	1.0		5.5
6		0.5		5.0
7		0.0		4.5
8				4.0
9				3.5
10				3.0
11				2.5
12				2.0
13				1.5
14				1.0
15				0.5
16				0.0

Table 4.2 Amount of infilatration under four types of land use

2 a Plot the speed of infiltration for the water at the four sites.
 b Describe the main differences in the infiltration curves of the four sites.
 c Suggest reasons to explain the differences that you have identified.

Storm or flood hydrographs

A **storm or flood hydrograph** shows how a storm affects a stream or river over a short period, such as over a few hours or up to a few days (Figure 4.6). These graphs show a number of features which vary from stream to stream. There are a number of key terms:

- **Discharge** is the amount (volume) of water passing a point over a given length of time. This is normally measured in litres per second or cubic meters per second (cumecs).
- **Peak flow** marks the greatest discharge of the stream.
- **Time lag** is the difference in time between the peak of the storm and the peak of the flood.
- The **rising limb** is the rising floodwater whereas the **recessional limb** is the declining floodwater.
- **Base flow** is the normal flow of the river, that is, water that passes through rocks to reach the river or stream.
- **Storm flow** or (**quickflow**) is the rapid flow that the storm creates. It usually flows over the surface to the stream, hence it gets into it quickly.

Key definition

Storm or flood hydrograph – the variation in discharge in a stream or river following one or more flood events.

These features fluctuate with a number of key variables. For example, as gradient increases, the peak flow increases and the time lag decreases. This is because an increased gradient leads to a greater amount of overland flow, and faster rates of overland flow. Similarly, as the number of streams or channels in an area increases (that is, the drainage density increases), peak flow increases and time lag decreases. This is because more water enters into streams (because there are more of them) and the channels transport the water rapidly away into the main river.

Monitoring a storm hydrograph

Monitoring storm hydrographs is difficult. You need a stream that is small enough so that it is not dangerous, close to where you live, and easily accessible. You will need to record rainfall as well as stream discharge. You will need to monitor the weather and have rain gauges in place for when a storm occurs.

Once the rain begins to fall you will be very busy for up to 48 hours. Ideally you will record the rainfall and discharge (cross-sectional area × velocity) every two to three hours, through the night as well. You will need to keep measuring until the river is back to its normal level.

ACTIVITIES

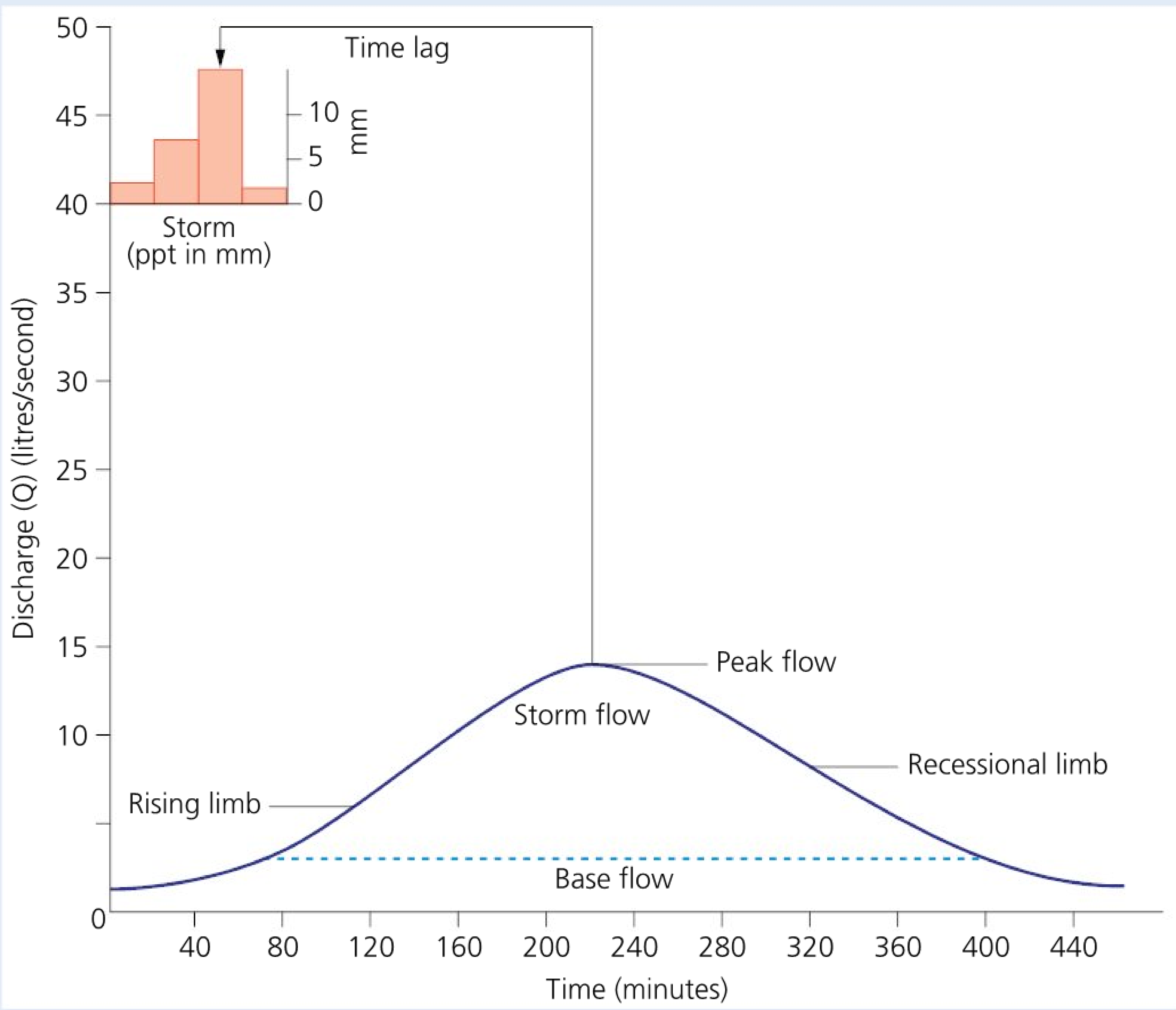


Figure 4.6 A flood event and a storm hydrograph in a rural area

3 Study Figure 4.6, which shows a flood event and a storm hydrograph in a rural area.

a On a copy of Figure 4.6, plot the figures in Table 4.3, which were derived from the same storm from a nearby urban stream.

b Identify the peak flow and time lag in the urban hydrograph.

c How do the rising limb and recessional limb in the new hydrograph compare with the original (natural) one?

d Explain these differences with reference to the increase in impermeable surfaces (pavements, roads, buildings, etc.) and number of drainage channels (sewers, gutters, drains, ditches, streams).

Time (minutes)	Discharge (litres/second)
0	4.4
30	8.0
60	20.0
90	35.0
120	44.0
150	36.0
180	26.0
210	18.5
240	14.0
270	9.5
300	7.5
330	6.5
360	6.0
390	5.5
420	4.0

Table 4.3 Recorded discharge over time for an urban stream

Monitoring water quality

Biological indicators: animals and plants

Some freshwater organisms have a very low tolerance of pollution. Some species (such as stonefly and mayfly) indicate good-quality water, whereas others (such as *Tubifex* worms and bloodworms) indicate poor-quality water. Some plants (such as sewage fungus and blanket weed) also indicate poor-quality water. Generally, water quality decreases towards the source of pollution.

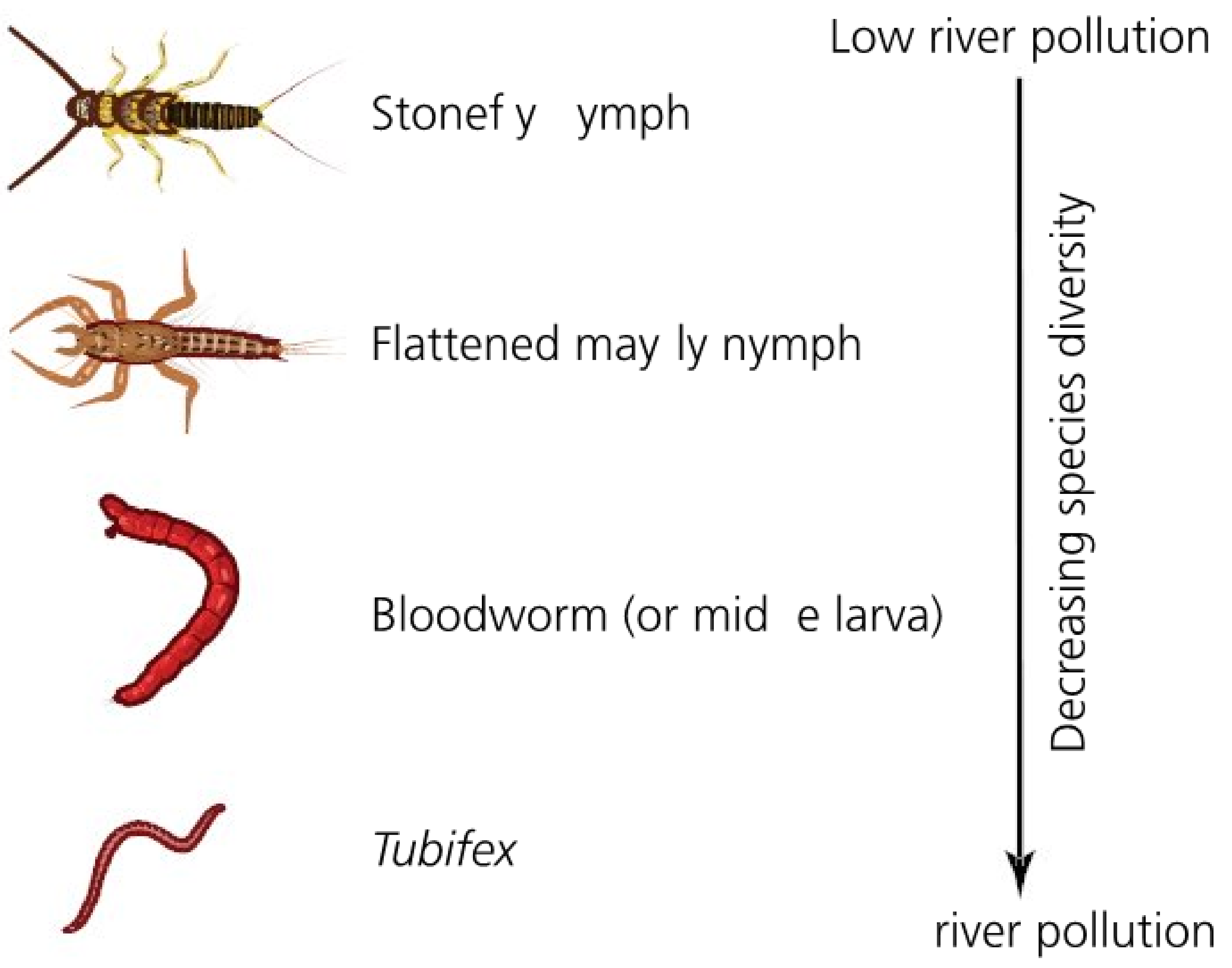


Figure 4.7 Invertebrate indicators of freshwater pollution

The effects of organic pollution are summarized in Figure 4.8, below.

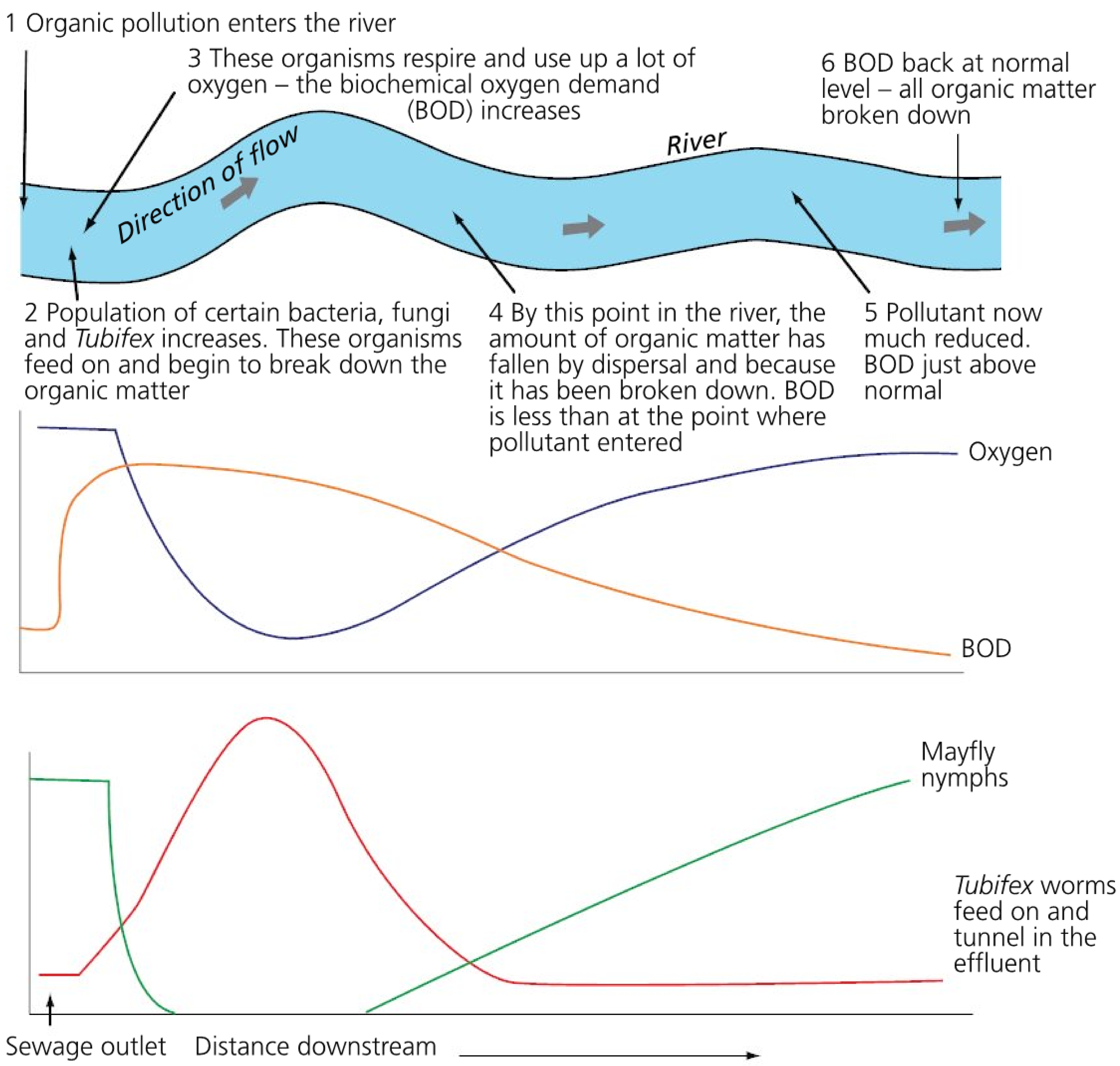


Figure 4.8 The effects of organic pollution

Visual evidence

Qualitative observations can be made regarding the water clarity (**turbidity**), odour, presence of oil or any rubbish in the stream or on the bank. Annotated photographs and field sketches can be used for presentation.

Expert tip

When assessing safety, ethics and environmental issues, you should ensure that the following are considered and included in your report:

- evidence of risk assessment
- an appreciation of the use of protective clothing/eye protection
- attempts to minimize the impact of the investigation
- return of all individual organisms safely to their natural environments.

Key definition

Turbidity – a measure of the amount of suspended sediment in a body of water, leading to discolouration and a 'murky' appearance.

Water quality report	Notes
1 Description of colour/turbidity	
2 Is there any odour?	
3 Are there any birds/mammals/amphibians/reptiles/insects?	
4 Is there any rubbish in the stream/on the riverbank?	
5 Is there any evidence of surface scum/oil/foam in the water or on the bank?	
6 Is there a water outfall present?	
7 Is there any sewage fungus or blanket weed present?	
8 Are there any signs of vandalism?	

Table 4.4 A visual evidence sheet

Turbidity

Turbidity is a measure of the amount of suspended sediment present in a water sample. A large amount of suspended sediment will give the water a turbid (dirty) appearance and this may indicate large amounts of organic pollutants in the water. To assess turbidity, use either a Secchi disc or a turbidity tube (Figure 4.9) which is lowered into the water, and the depth at which the markings can no longer be seen is recorded.

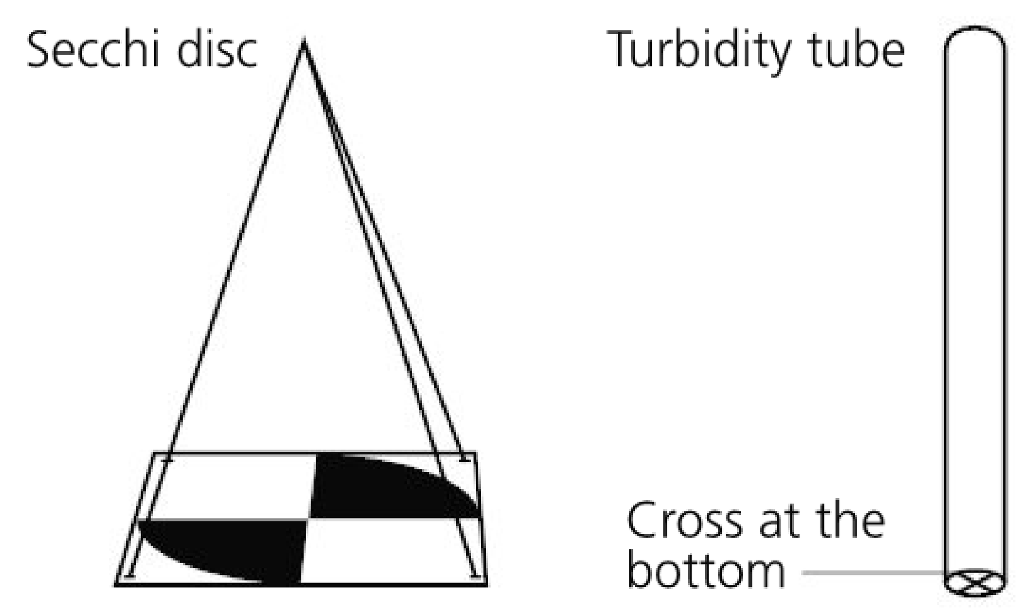


Figure 4.9 Secchi disc and turbidity tube

Temperature

Temperature partly limits stream oxygen levels: the lower the temperature, the more oxygen that can be dissolved in the stream. Temperature can easily be measured using a waterproof thermometer.

Chemical tests

Dissolved oxygen

Oxygen is used by bacteria to break down organic pollutants, therefore streams with low oxygen concentrations may be experiencing pollution, for example, from raw sewage. Low oxygen concentrations have an impact on societies, as fish are unable to survive in streams with low levels of oxygen, so a potential food supply is affected.

Oxygen levels can be assessed with a meter and probe, or by use of a specialized chemical testing kit. Typically, dissolved oxygen follows an idealized pattern (Figure 4.10).

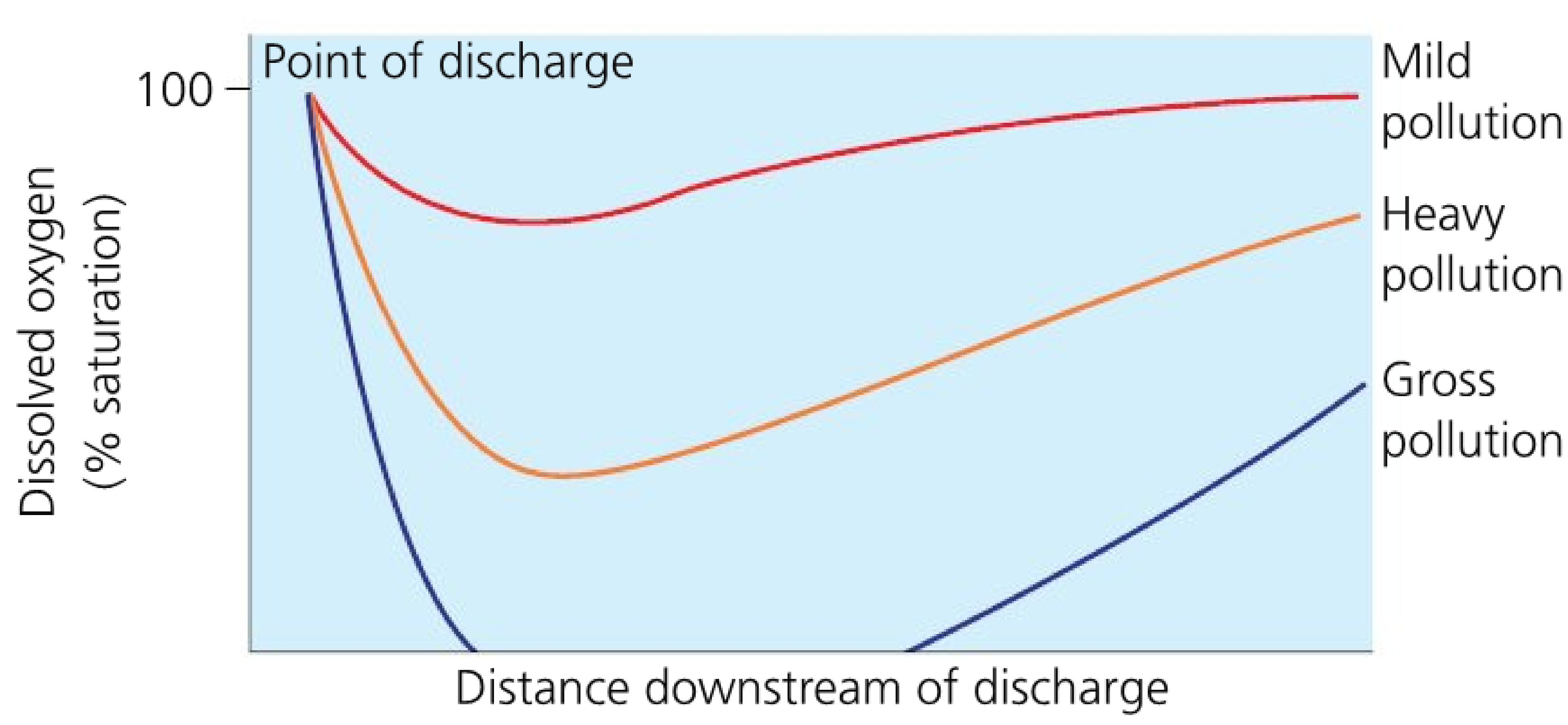


Figure 4.10 Changes in dissolved oxygen levels due to an organic discharge

Nitrate and ammonia levels

Nitrates are essential for plant growth, but levels of 50 ppm are the recognized limits for safe drinking water. High levels of nitrates may originate from agricultural fertilizers or manure and are associated with eutrophication. Test strips are available for the assessment of nitrate levels and ammonia levels.

pH

Changes in stream pH are quite complex and may not necessarily be related to a particular source. However, acidification of watercourses can be investigated, although it normally occurs over a very long time period. To measure pH, a pH probe and pH meter or test strips can be used.

Indicator	Methods	What the results show
Dissolved oxygen	Use a test kit, meter or sensor for dissolved oxygen. Follow the instructions to measure the amount of oxygen saturation in a sample of water. Oxygen concentration is usually measured in percentage saturation.	• Healthy clean water shows >75% oxygen saturation • Polluted water shows 10–50% oxygen saturation • Raw sewage contains 10% saturation of oxygen or less
pH	Dip pH or universal indicator paper into a sample of water. Compare the colour of the pH paper with the pH colour chart. Record the pH number (for example, pH 8).	• pH 1–6 indicates that the water is acidic • pH 1 is extremely acidic • pH 7 indicates a neutral solution • pH 8–11 indicates that the water is alkaline • pH 11 is very alkaline
Phosphate	Use a test kit. Follow the instructions to measure the amount of phosphate ions in a sample of water. Phosphate is measured in $mg\,dm^{-3}$.	• Clean water contains >5 $mg\,dm^{-3}$ phosphate • Polluted water contains 15–20 $mg\,dm^{-3}$ phosphate
Nitrate	Use a test kit. Follow instructions to measure the amount of nitrate ions in a sample of water. Nitrate is measured in mg dm	• Clean water contains 4–5 $mg\,dm^{-3}$ nitrate • Polluted water contains 5–15 $mg\,dm^{-3}$ nitrate
Salt (as chloride)	Use a test kit or meter or sensor. Follow the instructions to measure the amount of chloride ions in a sample of water. Salinity is measured in $mg\,dm^{-3}$	• Seawater contains 20 000 $mg\,dm^{-3}$ chloride • Tidal or brackish water contains 100–20 000 $mg\,dm^{-3}$ chloride
Ammonia	Use a test kit. Follow the instructions to measure the amount of ammonia in a sample of water. Ammonia is measured in $mg\,dm^{-3}$.	• Clean water contains 0.05–1.00 $mg\,dm^{-3}$ ammonia • Polluted water contains 1–10 $mg\,dm^{-3}$ ammonia • Raw sewage contains 40 $mg\,dm^{-3}$ ammonia

Table 4.5 Chemical indicators

Class of waterway	Fauna present	BOD/mg O_2 absorbed per dm^{-3} of water at 20 °C in 5 days	Waterway use
I	Fish such as salmon, trout, grayling, and insects such as stonefly and mayfly nymphs, caddis larvae, *Gammarus*	0–3	• Domestic supply
II	Fish such as trout rarely dominant; chub, dace, insects such as caddis larvae, *Gammarus*	4–10 (increased in summer in times of low flow)	• Agriculture • Industrial processes
III	Fish such as roach, gudgeon, insects such as *Asellus*, mayfly nymphs and caddis larvae rare	11–15	• Irrigation
IV	Fish absent, insects such as red chironomid larvae (bloodworms) and *Tubifex* worms present	16–30 (completely deoxygenated from time to time)	• Unsuitable for amenity use
V	Barren or with fungus or small *Tubifex* worms	>30	• None

Table 4.6 Biochemical oxygen demand and type of fauna present

The Trent biotic index

The **Trent biotic index** is based on the disappearance of indicator species as the level of organic pollution increases in a river. This occurs because the species are unable to tolerate changes in their environment such as decreased oxygen levels or lower light levels. Those species best able to tolerate the prevailing conditions become abundant, which can lead to a change in diversity. In extreme environments (for example, a highly polluted river), diversity is low, although numbers of individuals may be high. Diversity decreases as pollution increases. The Trent biotic index has a maximum value of ten. The indices are in the form of marks out of ten and give a sensitive assessment of pollution levels.

Key definitions

Biotic index – the use of animal species to make conclusions about the level of pollution.

Trent biotic index – the use of freshwater species to make conclusions about the level of pollution.

1. Sort your sample, separating the animals according to group.
2. Count the number of groups.
3. Note which indicator species are present, starting from the top of the list in Table 4.7.
4. Take the highest indicator species on the list and read across the row, stopping at the column with the appropriate number of groups for your sample.

So, if your highest indicator animal belongs to the *Trichoptera*, you have more than one species and a total of 7 groups, the Trent biotic index for your sample is 6.

		Total number of groups present				
		0–1	**2–5**	**6–10**	**11–15**	**16+**
Indicator groups present	**Number of species**	**Trent biotic index**				
Stonefly nymph (*Plecoptera*)	>1	–	7	8	9	10
	1	–	6	7	8	9
Mayfly nymph (*Ephemeroptera*)	>1	–	6	7	8	9
	1	–	5	6	7	8
Caddis fly larvae (*Trichoptera*)	>1	–	5	6	7	8
	1	4	4	5	6	7
Gammarus	All above groups absent	3	4	5	6	7
Shrimps, crustaceans (*Aseilus*)	All above groups absent	2	3	4	5	6
Tubifex and/or chironomid larvae	All above groups absent	1	2	3	4	–
All above groups absent	Organisms not requiring dissolved oxygen may be present	0	1	2	–	–

Table 4.7 Indicator species for the Trent biotic index

■ ACTIVITIES

4 The following data were collected from two sites on a stream, one upstream from a sewage outlet pipe, the other just below the outlet.

	Number of individuals	
Species	**Site 1 (below outlet)**	**Site 2 (upstream from outlet)**
Tubifex	38	3
Red tailed maggot	10	2
Freshwater shrimp	0	12
Swimming mayfly nymph	0	8
Caddis fly larvae	0	14
Flattened mayfly nymph	0	10
Stonefly	0	11
Total number of individuals	**48**	**60**

Table 4.8

a Calculate the Simpson's diversity index for the two sites using the equation:

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

b Work out the Trent biotic index for each site.

5 The diagram in Figure 4.11 shows a small stream which is joined by a tributary outlet that comes from a water treatment plant.

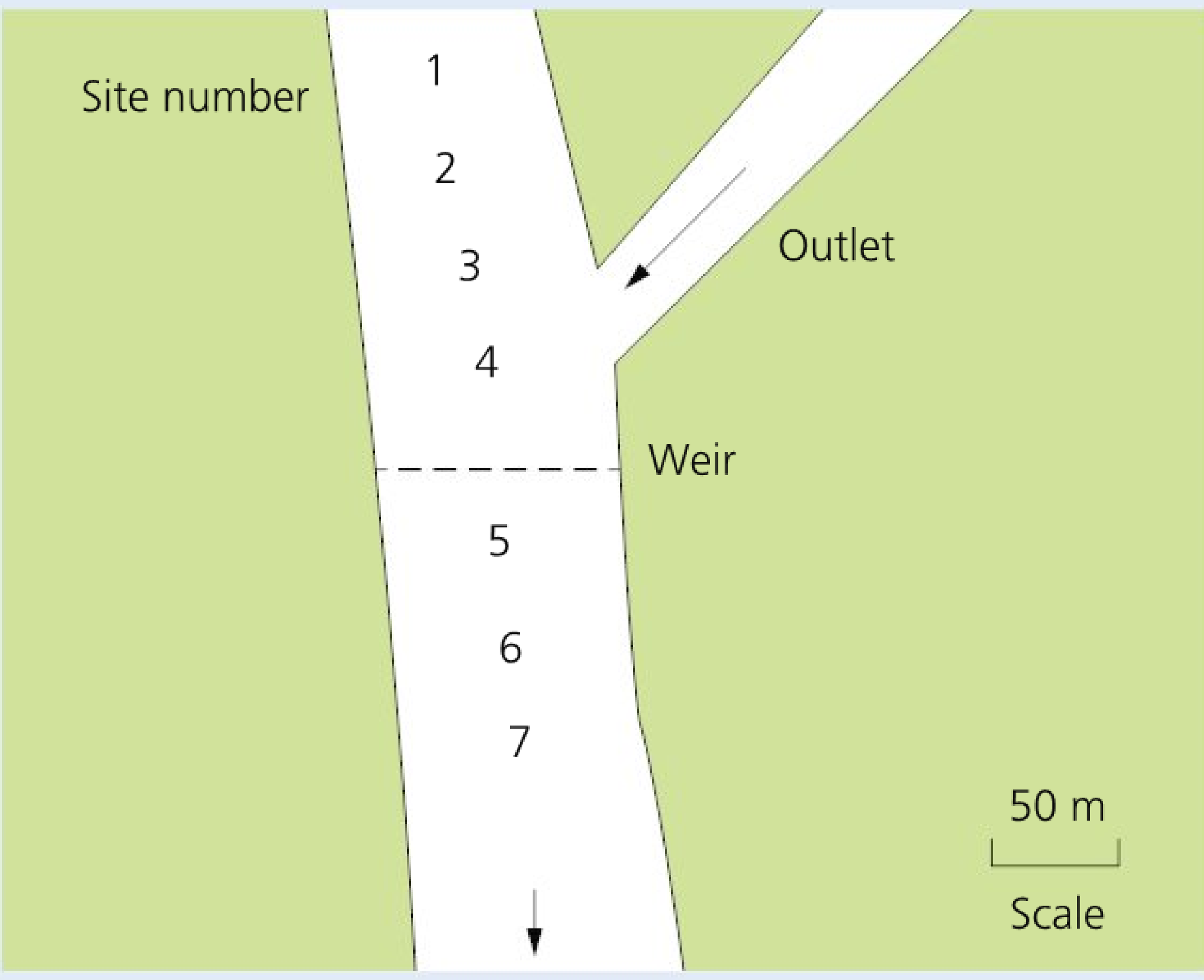


Figure 4.11 Sketch map to show the sample sites above and below a sewage outlet pipe

Site	Cross-sectional area (m^2)	Velocity ($m s^{-1}$)	Discharge ($m^3 s^{-1}$)	Temperature (°C)	Oxygen (%)	pH
1	2.1	0.2		18	0.1	6.0
2	2.3	0.2		17	0.2	6.0
3	2.2	0.3		18	0.1	7.0
4	3.8	0.3		23	0.3	6.5
5	3.9	0.6		22	1.8	7.0
6	4.1	0.8		22	1.7	7.5
7	3.9	0.7		20	1.6	6.5
8	4.0	0.7		22	1.5	7.0

Table 4.9 Summer readings

Site	Cross-sectional area (m^2)	Velocity ($m s^{-1}$)	Discharge ($m^3 s$)	Temperature (°C)	Oxygen (%)	pH
1	2.6	0.3		12	0.2	6.5
2	2.8	0.4		13	0.3	7.0
3	2.8	0.4		12	0.3	6.0
4	4.5	0.4		17	0.5	7.0
5	4.5	0.9		16	2.1	7.0
6	4.6	1.0		16	2.0	7.5
7	4.5	0.9		15	1.8	7.0
8	4.8	0.9		16	1.7	6.5

Table 4.10 Winter readings

a **i** Calculate the discharge for each of the sites in summer (Table 4.9) and winter (Table 4.10).

ii Explain how and why discharge varies between summer and winter.

b Plot the results for variations in oxygen content along the course of the stream. How does oxygen content change between sites 4 and 5? Suggest reasons for the changes.

c Outline the seasonal changes in temperature in the stream.

Ideas for investigations

- Infiltration varies under different types of vegetation.
- The amount of interception varies with vegetation type.
- Rainfall varies around a school environment/under different types of vegetation.
- Storm hydrographs vary between urban and rural areas.
- Indicator species vary above and below a sewage outlet.
- The distribution of bloodworms and stonefly nymphs are inversely proportional to each other.

ENVIRONMENTAL ISSUES

There are many environmental issues related to water systems. These include changes due to human activities (land use changes and global warming, for example), pollution of water systems (disposal of waste and agricultural run-off, for instance), impacts of water management (for example, afforestation) and changing access to water.

5 Soil systems

Soils

Soils form the outermost layer of the Earth's surface (Figure 5.1a), comprising weathered bedrock (regolith), organic matter (both dead and alive), air and water. The formation of a layer of 30 cm of soil takes between one thousand and ten thousand years. It is formed so slowly that soil can be considered a non-renewable resource.

Soils develop from the weathering of bedrock into progressively finer particles. Biological processes in the soil, such as mixing by earthworms, result in further development. The nature of the bedrock, climate, topography, vegetation and land use influence the extent of weathering and the nature and properties of the soil that develops. Soils can therefore vary significantly over very small areas (Figures 5.1b–d), even within a single field, depending on local changes in parent material, slope and aspect. Soils allow us to obtain a great deal of information from a small area of study.

Figure 5.1a A soil (and rocks) formed under intense freezing and thawing, Loop Head, Ireland

Figure 5.1b A **podzol** with distinct horizon development

Figure 5.1c A brown earth with unclear horizon development

Figure 5.1d A **rendzina** with limited horizon development

Soil has matter in all three physical states:

- Organic and inorganic matter form the solid state.
- Soil water (from precipitation, groundwater and seepage) form the liquid state.
- Soil atmosphere makes up the gaseous state.

Key definition

Soil – a mix of mineral particles and organic matter that covers the land and in which most plants grow.

Key definitions

Podzol – a type of soil formed under very acidic conditions, and therefore with no earthworm activity, with very distinct soil horizons.

Rendzina – a type of soil found on chalk or limestone, consisting of organic-rich material on top of bedrock.

Expert tip

The more you can study soils at your school, college or at home, the easier it will become and the greater your understanding will be. You will see how they vary in terms of depth, colour, pH, horizon development, moisture content, organic content and so on.

Soil atmosphere and water are present in inverse proportions. After a storm there is an increase in the water content at the expense of air.

The maximum amount of water that a soil can hold is referred to as **field capacity** Above this the soil is saturated and overland run-off will occur (as will happen if the rainfall intensity exceeds the infiltration rate, that is, the speed at which water can enter the soil).

Field capacity depends on a number of factors including texture, organic-matter content and density. During the winter, the soils often reach field capacity. With free drainage, excess water drains through the soil. Impeded drainage, however, results in waterlogging. In the spring there comes a point where the loss of water by plant uptake and evaporation exceeds the amount of rainfall and the soil begins to dry out. A **soil moisture deficit** develops and this is measured as the amount of rainfall required to return the soil to field capacity.

Soil depth

This can be measured by using a soil auger or a shovel to dig down as far as the underlying bedrock. For schools in urban areas, many soils may occur on top of loose, unconsolidated rubble (brick, concrete and mortar). Such debris may effectively be the bedrock. Soil depth can then be recorded in centimetres. Possible investigations include variations in soil depth with slope angle, landscaping, or position on a slope (for example, top, middle and base). Ironically, many tropical soils, although very deep, are low in organic matter and not very fertile, so soil depth does not necessarily mean fertile soils.

Worked example

The following data were collected on slopes at Shotover, Oxford, in the UK.

Using the data below for slope angle and soil depth, investigate whether there is any statistically significant correlation between slope angle and soil depth.

Slope angle (°)	5.5	11.5	12.0	13.0	25.0	22.0	18.0	26.0	20.0	3.0
Soil depth (cm)	60.0	48.0	33.0	18.0	22.0	29.0	24.0	24.0	12.0	60.0

Table 5.1 Slope angle and soil depth at Shotover, Oxford, UK

1 State the **null hypothesis**.

2 Create a table so that you can enter the raw data and later work out the correlation.

3 Rank both sets of data from high to low (highest = rank 1).

4 Calculate the difference in ranks.

5 Calculate the square of the differences.

6 Calculate the figures in the final column to find $\sum d^2$

7 Using this figure, determine the correlation between soil depth and slope angle:

$$R_s = 1 \quad \frac{6\sum d^2}{n^3 \quad n}$$

8 Compare your answer with the critical values in a statistical table (see Table 9.14 on page 134). What is the significance of your result?

Working out

Null hypothesis: there is no relationship between slope angle and soil depth.

Alternative hypothesis: there is a relationship between slope angle and soil depth.

Key definitions

Hypothesis – there **is** statistically significant relationship (correlation) between two variables.

Null hypothesis – there is **no** statistically significant relationship (correlation) between two variables.

Slope angle (°)	Soil depth (cm)	Rank slope angle	Rank soil depth	Difference in ranks (d)	Difference squared (d^2)
5.5	60.0	9.0	1.5	7.5	56.25
11.5	48.0	8.0	3.0	5.0	25.00
12.5	33.0	7.0	4.0	3.0	9.00
13.0	18.0	6.0	9.0	3.0	9.00
25.0	22.0	2.0	8.0	6.0	36.00
22.0	29.0	3.0	5.0	2.0	4.00
18.0	24.0	5.0	6.5	1.5	2.25
26.0	24.0	1.0	6.5	5.5	30.25
20.0	12.0	4.0	10.0	6.0	36.00
3.0	60.0	10.0	1.5	8.5	72.25
					$\Sigma d^2 = 280$

Table 5.2

$$R = 1 \quad \frac{6\Sigma d^2}{n \quad - n}$$

$$= 1 - \frac{6 \times 280}{10^3 - 10}$$

$$= 1 \quad \frac{1680}{990}$$

$$= 1 - 1.697$$

$$= -0.697$$

The critical value for a sample of 10 is 0.648 at the 95% confidence level. Here, it is clear that there is a strong relationship (at the 95% level) and we can reject the null hypothesis and accept the alternative hypothesis.

The soil profile

A **soil profile** is a two-dimensional section through a soil and refers to the different layers that can be observed within a soil. Some soils have very clear profiles, such as that in Figure 5.1b on page 64, due to very acidic conditions and the lack of earthworm activities (podzols). Others, such as that in Figure 5.1d on page 64 are very simple, as the main process is carbonation solution which removes bedrock and leaves a small organic layer resting on the rock (rendzinas).

Key definitions

Soil profile – a vertical section through a soil, from the surface down to the parent material (bedrock), which shows the soil layers or horizons.

Soil horizons – the horizontal layers within a soil distinguished by their colour, chemical composition, permeability and texture.

Observing soil horizons

The characteristics and properties of soil often vary with depth. The soil profile is seen by examining a vertical exposure of a soil or in a soil pit. Dig to a depth where there is no further change in the appearance of the soil. Avoid compressing the soil or smearing the cut surface with the shovel. If necessary, clean the walls of the pit with a knife. Draw a profile of the soil, noting the colour, thickness, structure, texture and depth of each **horizon**

Appearance of the soil

A thick brown soil suggests a high organic content. A soil may be grey or ash coloured because the nutrients have been leached (washed) out of it. Leaching is most likely if the soil has a sandy texture. Clay soils may be blue-grey or blotchy brown-red. The blue-grey colour suggests iron in the reduced-iron state, that is, the absence of oxygen due to waterlogging. In contrast, a reddish-brown colour indicates the presence of oxidized iron, that is, the presence of oxygen and good aeration.

The colour of the soil is best described in natural daylight, taking a smear from damp soil.

Measuring soil pH

pH is important as it affects the mobility of certain chemicals. Other chemical tests can be carried out to measure the levels of nutrients in the soil. Some of these are available from garden centres. They are all quite basic but will show strong contrasts in soils.

A pH test can be carried out using a universal indicator, as follows:

1 Take a small soil sample from a known depth (horizon) of soil.
2 Place about 1–2 cm of soil in the bottom of a test tube.
3 Add 1–2 cm of barium sulphate solution (this causes the clay to settle, leaving a clear solution).
4 Fill the tube with distilled water and shake.
5 Add a few drops of universal indicator to clear the solution. Compare the colour of the solution to the colour chart provided. The pH can be read off to the nearest 0.5.

Alternatively, a digital pH probe and meter can be used.

Soil texture

Soil texture refers to the size of the solid particles in a soil, ranging from gravel to clay. The proportion of each type of particle varies from soil to soil and within each soil in the horizons. This gives rise to soil textural groups, which are differentiated in relation to the amount of sand, silt and clay present.

Key definition

Soil texture – the size of particles in a soil, notably sand, silt and clay.

Type of particle	Diameter (mm)
Clay	<0.002
Silt	<0.02
Fine sand	<0.2
Coarse sand	<2
Gravel	>2

Table 5.3 Soil textural groups

Most soils are composed of sand, silt and clay particles. These may be bound together with organic matter or other cementing agents to form aggregates. Sandy soils usually have a weak structure, and the large spaces between the coarse particles allow rapid drainage of water. This limits the amount of water that is retained in the soil and available for plant growth. It also increases the risk of leaching of nitrate ions and pesticides into surface waters and into aquifers, especially where soils overlie permeable rocks such as limestone and sandstone.

Soils with a high clay content have very different properties. The spaces between the individual particles are considerably smaller than between sands and silts. This greatly impedes the drainage of water. Some clays are, however, well structured. In these soils individual soil blocks are separated by relatively large fissures which allow drainage. Under very dry conditions excessive shrinkage of soils with a high clay content can cause structural damage to houses built on them. Under average climatic conditions, clay shrinkage is not a major problem. However, in major dry periods such as 1976 and 2018, extensive subsidence damage was caused.

Silty soils, especially those with a low organic-matter content, often have a weak structure and are susceptible to water logging. This can restrict seedling germination and increase the risk of erosion. The physical and chemical properties of **loam soils** will depend on the relative proportion of sand, silt and clay. Loam soils with a mix of sand, silt and clay may have an optimum capacity for holding sufficient water to support plant growth and the optimum combination of air-filled pores necessary for good root growth.

Key definition

Loam soil – a mixed soil consisting of sand, silt and clay.

Soil texture is important as it affects:

- moisture content and aeration
- retention of nutrients
- ease of cultivation and root penetration.

Figure 5.2a Sieving soil

Figure 5.2b Sieved textural groups

Expert tip

Take two (or more) contrasting soils. Dry them in an oven at 100 °C for 24 hours, then weigh them. Put them through a series of sieves to work out their textural groups.

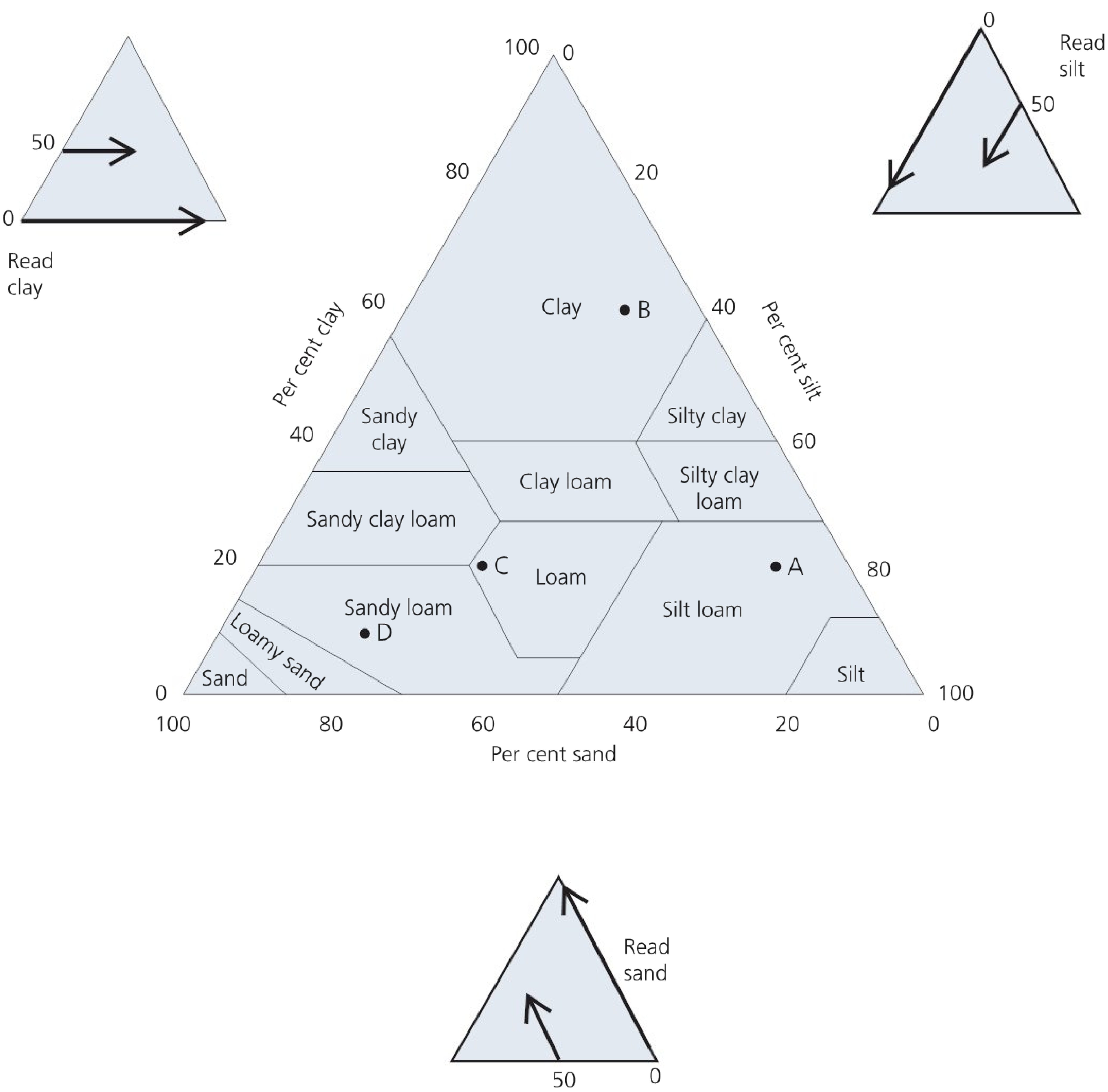


Figure 5.3 A triangular graph showing soil textural groups

The conventional way of representing texture is by means of a triangular graph. Triangular graphs are used to show data that can be divided into three parts. This includes soil (sand, silt and clay), employment (primary, secondary and tertiary) and population (young, adult and elderly). Figure 5.3 shows a triangular graph for soil. The data must be expressed in percentages and the total must add up to 100%. The main advantages of a triangular graph are that:

- a large number of data can be shown on one graph (consider how many pie charts or bar charts would be needed to show all the data on Figure 5.3)
- groupings are easily recognizable – in the case of soils, groups of soil texture can be identified
- dominant characteristics can be shown easily
- classifications can be drawn up.

Triangular graphs can be difficult to interpret and it is easy to get confused, especially if you do not take care. However, they provide a fast and reliable way of classifying large amounts of data which have three components.

Common mistake

Do not confuse soil texture with soil structure. Texture refers to the **size** of the soil particles whereas structure refers to their **shape**

ACTIVITIES

1 a Identify the soils marked A, B, C and D on Figure 5.3 on page 68
b Plot the following soils on a triangular graph:
i Clay 30%, sand 25% and silt 45%
ii Clay 45%, sand 35% and silt 20%
iii Clay 22%, sand 37% and silt 41%
iv Clay 37%, sand 36% and silt 27%
c Identify the textural groups they belong to.

Assessing soil texture

The texture of the soil refers to the size of the particles that form the soil. Soil texture can be assessed by rubbing a fresh sample of soil between your fingertips. This is a very subjective method and results are likely to vary between individuals.

Soil texture can also be assessed by sieving air-dried soil through a set of sieves with graded meshes. Add a known mass of soil to the top sieve, and then after prolonged sieving, note the mass of soil in each of the individual sieves.

The soil should feel slightly damp. If the soil is waterlogged an allowance should be made. Pass the soil gently through the fingers and thumb. Use Table 5.4 to help you to make an assessment of the texture:

1 Does the soil form a coherent ball?	
Easily	(Move to test 2)
With great care	Loamy sand (But check using test 2)
No	Sand
2 What happens when the ball is pressed between the thumb and forefinger?	
Flattens coherently	(Move to test 3)
Tends to break up	Sandy loam (But check using tests 3 and 4)
3 On slight further moistening, can the ball be rolled into a thick cylinder (about 5 mm thick)?	
Yes	(Move to test 4)
No, ball collapses	Sandy loam
4 On slight further moistening, can the ball be rolled into a thin cylinder (about 2 mm thick)?	
Yes	(Move to test 5)
No	Sandy loam
5 Can the thread be bent into a horseshoe without cracking, for example, around the side of the hand?	
Yes	(Move to test 7)
No	(Move to test 6)
6 On remoulding with further moisture, what is the general 'feel' of the soil?	
Smooth and pasty	Silty loam
Rough and abrasive	Sandy silt loam

7 Can a ring of about 25 mm in diameter be formed by joining the two ends of the thread without cracking? (If necessary, remould with more moisture and begin again.)	
Yes	(Move to test 9)
No	(Move to test 8)
8 On remoulding with further moisture, what is the general 'feel' of the soil?	
Very gritty	Sandy clay loam
Moderately tough	Clay loam
Doughy	Silty clay loam
9 On remoulding without rewetting, can a surface be polished with the thumb?	
Yes, a high polish	(Move to test 10)
Yes, but gritty particles are very noticeable	Sandy clay
No	(Move to test 8)
10 On wetting thoroughly, how does the soil stick your fingers together?	
Very strongly	Clay
Moderately strongly	Silty clay

Table 5.4 Finger assessment of soil texture

Soil porosity

Push an empty tin into the ground to the depth of the can (any further pushing will compress the soil and reduce the porosity). Calculate the volume of soil from the formula $\pi r^2 h$, where r is the radius of the can and h is the height of the can. Add the soil to a large measuring cylinder. Add a known volume of water and mix the soil thoroughly so that all the air is displaced from it and bubbles to the surface of the water. Note the volume of water and soil.

Calculate the porosity of the soil using the following equation:

$$\text{percentage porosity} = x - (z \quad y) \times \frac{100}{x}$$

where

x = the original volume of soil (or can)

y = the volume of water used

z = the final volume of water and soil

Common mistake

Do not confuse porosity with permeability. Porosity is the ability to **hold** water – some soils such as clay can hold large volumes of water. Permeability is the ability to **transmit** water. Sandy soils are very permeable; clay, on the other hand, is not very permeable.

Worked example

Soil type and soil moisture

A survey of 20 soils (10 **gleyed** soils and 10 brown earths) was undertaken to investigate soil moisture. The results are shown below.

Gleyed soils (% moisture content)	Brown earths (% moisture content)
33	20
27	23
28	19
32	24
36	26
25	21
31	22
26	25
25	25
28	24

Table 5.5 Soil moisture in gleyed soils and brown earths

Key definition

Gleyed soil – a waterlogged soil.

The Mann-Whitney *U* test is used to test whether the mean of two independent samples is statistically different, that is, whether the samples come from different populations. It is used when two populations are not normally distributed.

Procedure

1 The null hypothesis, H_0, states that there is no difference in the means of the two samples. It assumes that the differences between them are the result of chance and are not significant.

2 The alternative hypothesis, H_1, is that there is a significant difference between the two samples, in this case that gleyed soils have a higher moisture content than brown earths.

3 The critical level is 95%.

4 To apply the statistic, the values must be placed in rank order but kept in their groups. (Conventionally, the smallest value is given rank 1. Where values tie, assign an average rank to each value.)

Gleyed soils: 19.0, 13.5, 15.5, 18.0, 20.0, 9.5, 17.0, 13.5, 9.5, 15.5 $\quad \Sigma R_1 = 151$

Brown earths: 2.0, 5.0, 1.0, 6.5, 12.0, 3.0, 4.0, 9.5, 9.5, 6.5 $\quad \Sigma R_2 = 59$

The Mann-Whitney formula is

$$U_1 = n_1 n_2 + \frac{1}{2} n_2(n_2 + 1) - \Sigma R_2$$

or

$$U_2 = n_1 n_2 + \frac{1}{2} n_1(n_1 + 1) - \Sigma R_1$$

where ΣR_1 = the sum of the ranks given to values in n_1

and ΣR_2 = the sum of the ranks given to the values in n_2

Thus:

$$U_1 = n_1 n_2 + \frac{1}{2} n_2 (n_2 + 1) - R_2$$

$$= (10 \times 10) + \left(\frac{1}{2} \times 10\right)(10 + 1) - 59$$

$$= 96$$

$$U_2 = n_1 n_2 + \frac{1}{2} n_1(n_1 + 1) - \Sigma R_1$$

$$= (10 \times 10) + \left(\frac{1}{2} \times 10\right)(10 + 1) - 151$$

$$= 4$$

5 Referring to the statistical tables, the lower *U* value is used, in this case 4. In order for it to be significant, it must be lower than the critical values in the table. In the significance tables, the value for N_1 and N_2 is 28 at the 0.05 level. Hence, we are more than 95% certain that given the data above, there is a significant difference in the moisture content of the soil types (since the lower *U* value of 4 is less than the critical value of 28). We would therefore reject the null hypothesis which states that there is no difference in the moisture content of gleyed soils and brown earths.

Variations in soil temperatures

Soil temperature is important for germination and plant growth. In general, sandy soils are quite light and become very warm as there is little water present in the soil. In contrast, clay soils contain more water and heat is used to evaporate the water rather than just heating the soil. Thus, clay soils are considered to be quite cold.

Examiner guidance

Remember to use data to support your answer. You should read off the data from the graph provided.

Ideas for investigations

1. Choose two or more contrasting locations where you could investigate soil temperature. Justify your choices. (Can you carry out this experiment at your college or near your home, possibly in a back garden? Remember that safety is an important issue and you do not want to be recording soil temperatures alone in a well-vegetated area around dusk.)
2. To measure soil temperature you will need a thermometer. You could take a reading at the surface and at a depth of 10 cm. What changes would you expect to find between the surface and 10 cm?
3. You could record temperatures at the sites over a day (dawn to dusk), or over an extended period of time, recording at the same time on each occasion. Why is this important?
4. Outline the implications of soil temperatures for societies. Can you think of at least one impact it has on the societies in question?

ACTIVITIES

2 The following graph shows changes in temperature with soil type.

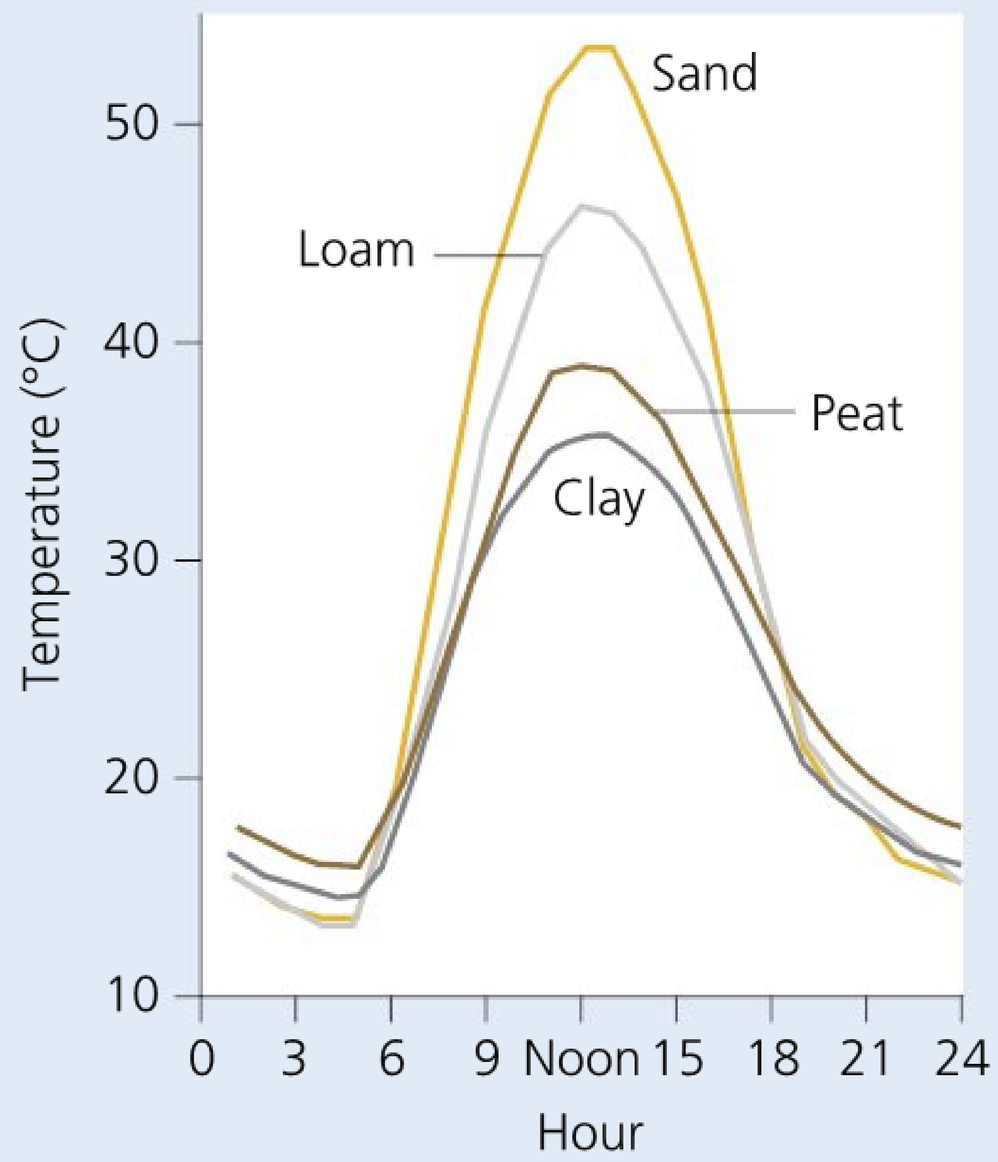


Figure 5.4 Changes in temperature with soil type

a Analyse the data shown on the graph.
b Suggest possible implications of this for farmers.

Soil surface	Temperature (°C)			
	10.00 hours	12.00 hours	14.00 hours	16.00 hours
Bare soil	8.4	11.8	16.1	15.7
Grass covered	3.2	4.3	6.2	7.4

Table 5.6 Temperatures (°C) under bare soil and grass-covered soil (at a depth of 10 cm)

c Analyse the main differences between the soil temperatures of bare soil and that under grass.
d Suggest how this might vary in winter. Give reasons for your answer.

Investigating soil moisture content and organic content

Soils vary considerably in their moisture content and organic content. Measuring these is quite easy. Take a sample of soil with a soil auger or a small trowel and place a handful of it in an airtight bag (for transportation). In the lab, weigh a sample of the soil (S_1), place it in an oven and burn it at 100 °C for 24 hours. Reweigh the sample (S_2).

Calculate the moisture content using the formula:

$$\text{moisture content} = \frac{S_1 \quad S_2}{S_1} \quad 100$$

To work out organic content take the sample (S_2) and burn it over a Bunsen burner at maximum temperature for fifteen minutes. Reweigh the burned sample (S).

Examiner guidance

Rather than just 'lifting' data, for which you will gain no credit, if you manipulate the data you will gain some credit. For example, if you say at 14.00 hours the bare soil is 16.1 °C and the temperature of the soil under grass is 6.2 °C, you will gain no credit as that information is given to you. However, if you state that the temperature of the bare soil is 9.9 °C warmer than that of the soil under the grass, you have manipulated the data and will gain some credit.

Calculate the organic content using the formula:

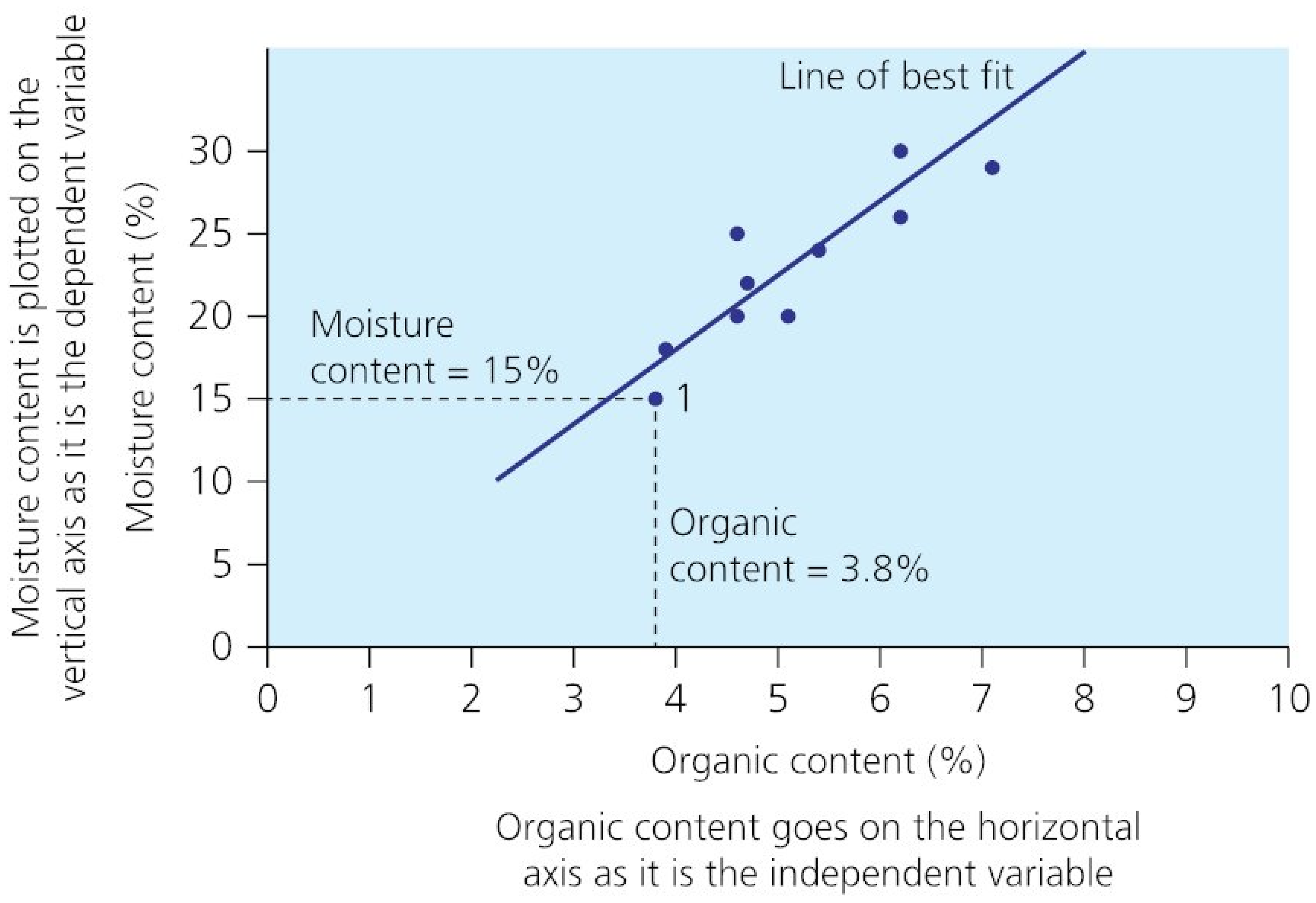
$$\text{organic content} = \frac{S_2 - S_3}{S_2} \times 100$$

Worked example

Investigating the link between soil organic content and soil moisture content

Sample	Organic content (OC) (%)	Moisture content (MC) (%)
1	3.8	15.0
2	4.7	22.0
3	6.2	30.0
4	3.9	18.0
5	5.4	24.0
6	7.1	29.0
7	6.2	26.0
8	4.6	20.0
9	4.6	25.0
10	5.1	20.0

Table 5.7 Soil organic content and moisture content



1 To plot each point, work out where the moisture content and organic content meet (point 1 has been drawn for you)

2 Label the points, if there is space. This is especially useful for identifying anomalies (exceptions) to the trend.

3 Draw a line of best fit.

Figure 5.5 Scatter graph to show the relationship between soil organic content and soil moisture content

Procedure

1. State the null hypothesis (H_0), i.e. that is there is no statistically significant relationship between the organic content (OC) and the moisture content (MC). The alternative hypothesis (H_1) is that there is a statistically significant relationship between the two variables.
2. Rank both sets of data from high to low, that is, the highest value gets rank 1, second highest gets 2, and so on. In the case of joint ranks find the average rank, for example, if two values occupy positions 2 and 3, they both take on rank 2.5, if three values occupy positions four, five and six, they all take rank 5.
3. Using the formula

$$R_s=1 \frac{6\sum d^2}{n^3 - n}$$

work out the correlation where d refers to the difference between ranks and n refers to the number of observations.

4. Compare the calculated values of R_s with the critical values in the statistical tables.

Sample	OC	MC	Rank OC	Rank MC	Difference in ranks *d*	d^2
1	3.8	15	10.0	10.0	0	0.00
2	4.7	22	6.0	6.0	0	0.00
3	6.2	30	2.5	1.0	1.5	2.25
4	3.9	18	9.0	9.0	0	0.00
5	5.4	24	4.0	5.0	–1	1.00
6	7.1	29	1.0	2.0	–1	1.00
7	6.2	26	2.5	3.0	–0.5	0.25
8	4.6	20	7.5	7.5	0	0.00
9	4.6	25	7.5	4.0	3.5	10.25
10	5.1	20	5.0	7.5	–2.5	6.25
						$\Sigma d^2 = 21$

Table 5.8 Worked example

$$R_s = 1 - \frac{6\Sigma d^2}{n^3 \quad n}$$

$$= 1 - \frac{6(n \times 21)}{10^3 - 10}$$

$$= 1 - \frac{126}{990}$$

$$= 1 - 0.13$$

$$= 0.87$$

Once we have the computed value, we compare it to the critical values. For a sample of 10, these values are 0.564 for 95% significance and 0.746 for 99% significance. In this example it is clear that the relationship is very strong; *that is,* there is more than a 99% chance that there is a relationship between the data.

The next stage would be to offer a scientific explanation for the relationship.

The effects of trampling

Soil compaction is a major problem around the world. It can be caused by the use of farm machinery on the land, compaction by livestock around a waterhole, or trampling by people. Trampling by people is a major environmental factor influencing soils and vegetation in urban and rural environments. It is especially pronounced on sports fields and can be easily assessed by investigating soil moisture and organic content.

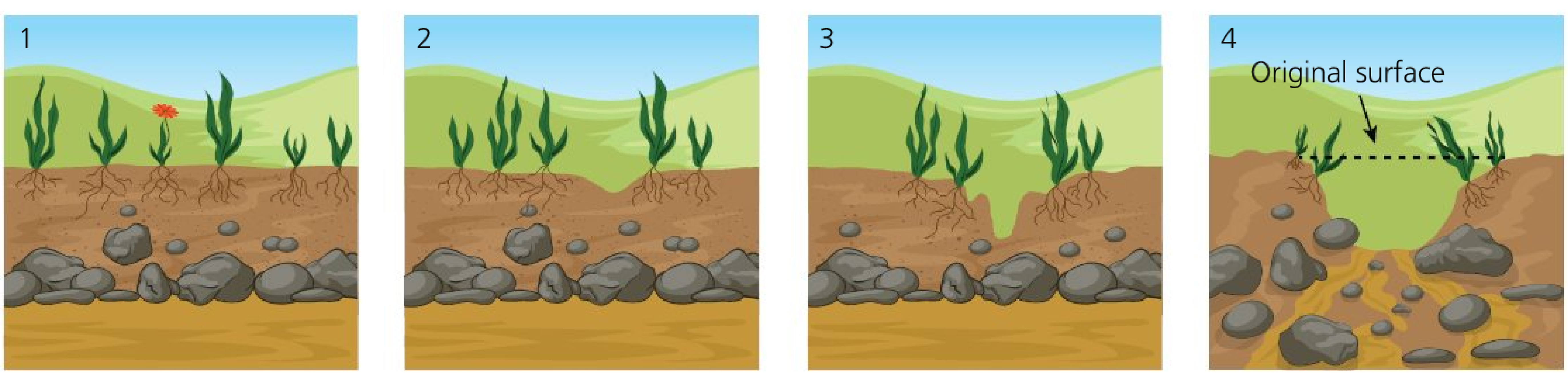


Figure 5.6 Stages in footpath erosion

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 run-off 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.

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.

Footpath erosion

Figure 5.7 The effects of trampling on a footpath on Croagh Patrick, County Mayo, Ireland

ACTIVITIES

3 The following data were taken across a footpath near Mitcham Junction, in Surrey (UK). Sites 1–3 were on one side of the footpath, and sites 5–7 on the other. Site 4 was the centre of the footpath.

Site	Moisture content (%)	Organic content (%)	Distance from the centre of the path (m)
1	29.4	10.6	3
2	16.8	7.9	2
3	9.1	5.2	1
4	7.3	3.8	0
5	10.3	6.2	1
6	18.6	7.9	2
7	25.6	10.5	3

Table 5.9

a Choose an appropriate graphical technique to show the variations in organic content and moisture content.

b Using the data, analyse the changes in moisture content and organic content across the footpath.

c Briefly outline the impact of footpath erosion for societies.

Worked example

Analysing the relationship between rock type and soil type

A survey of soils in south Devon (UK) found the following results.

Soil type	Sandstone	Granite	Clay
Brown earth	32	24	28
Gleyed (waterlogged) soil	12	16	22

Table 5.10 A sample of soil type and geology

Figure 5.8 A gleyed soil

It is possible to test whether there is a difference in the type of soil associated with the three rock types, using the χ^2 test (chi-squared test). The χ^2 test is used to test whether there is a difference in an observed pattern or a theoretical pattern.

Start by stating a null hypothesis, in this case that there is no statistically significant difference in the soil type with respect to different rock types. The alternative hypothesis would simply state that there is a statistically significant difference in the soil types associated with the three rock types.

Next, find the expected values (E) if there was an equal proportion of each soil type on each rock type. For this you will need the formula

$$E = \frac{\Sigma r \, \Sigma k}{n}$$

where

Σr = the sum of the rows

Σk = the sum of the columns

n = the total number of observations.

Soil type	Sandstone	Granite	Clay	Σr
Brown earth	32	24	28	84
Gleyed (waterlogged) soil	12	16	22	50
Σk	44	40	50	134

Table 5.11 Working out expected values for the χ^2 test

To find the expected values, multiply the row total by the column total and divide by n.

Soil type	Sandstone	Granite	Clay
Brown earth	$\frac{84 \times 44}{134} = 28$	$\frac{84 \times 40}{134} = 25$	$\frac{84 \times 50}{134} = 31$
Gleyed (waterlogged) soil	$\frac{50 \times 44}{134} = 16$	$\frac{50 \times 40}{134} = 15$	$\frac{50 \times 50}{134} = 19$

Table 5.12 Working out expected values for the χ^2 test (values rounded)

We can now continue to work out the χ^2 given that we have *O* and *E*.

Rock type/soil	Observed frequency (*O*)	Expected frequency (*E*)	*O*–*E*	(*O*–*E*)	$\frac{(O-E)^2}{E}$
BE/Ss	32	28	4	16	0.50
BE/Gr	24	25	1	1	0.04
BE/Cl	28	31	3	9	0.30
Gl/Ss	12	16	4	16	1.00
Gl/Gr	16	15	1	1	0.01
Gl/Cl	22	19	3	9	0.47
					$\sum = 2.32$

Table 5.13 Working out the χ^2 test

The next stage is to calculate the degrees of freedom (*df*). In this sort of chi-squared test where there are more than two categories, we use the formula:

$df = (\;\; - 1) \times (\;\; - 1)$

where *r* and *k* refer to the number of rows and columns respectively.

Thus, in this example:

$(3 - 1) \times (2 - 1) = 2 \times 1 = 2$

When we compare the computed value (2.32) against the critical values, we find that the critical values are 5.99 at the 95% level and 9.21 at the 99% level of significance. So, in this case we cannot reject the null hypothesis, and we would conclude that there is no statistically significant difference in the soil types associated with each of the three rock types in south Devon (UK).

Ideas for investigations

- The effect of trampling on soil degradation.
- The effect of soil type on soil temperature.
- The effect of location/soil type on soil moisture content.
- The effect of soil texture on soil temperature/moisture content.
- The influence of soil pH on plant distribution.

ENVIRONMENTAL ISSUES

There are a range of issues related to soils including degradation, conservation, impact on plant productivity and agricultural yield. These should be related to the local-scale effects that you are investigating as well as the large-scale impacts associated with the environmental issue.

6 Atmospheric systems and societies

Weather and climate

When we consider **weather**, we normally look at timescales of less than one week. Weather includes temperature (maximum and minimum), precipitation (type and amount), relative humidity, air pressure, wind speed and direction, and cloud cover. The same features can be measured for **climate** as for weather.

Key definitions

Climate – the extremes and average of weather conditions for an area over a time of not less than 30 years.

Weather – the state of the atmosphere over a very short time (generally less than one week).

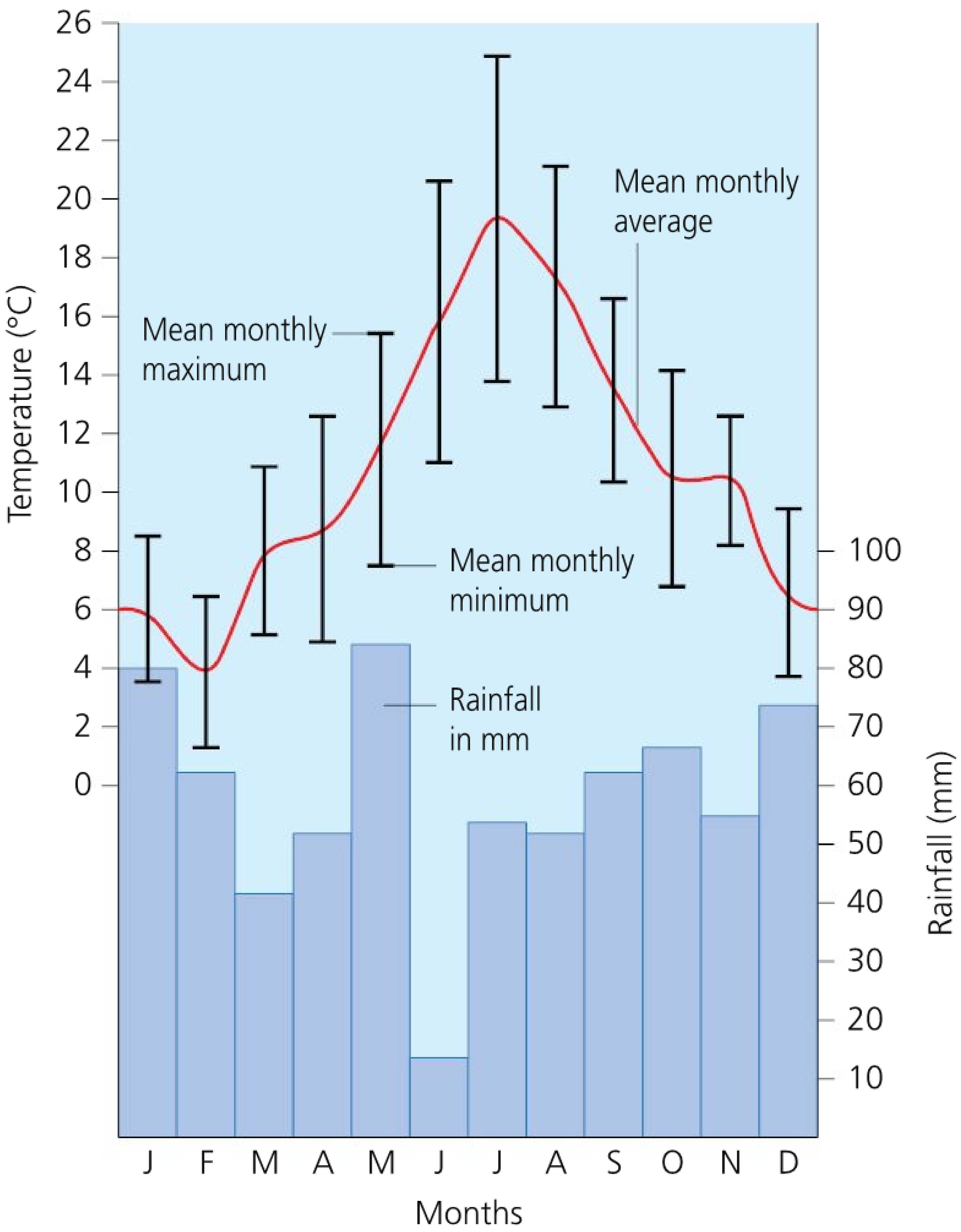


Figure 6.1 A climate graph (climograph)

Simple climate graphs (or climographs) tell us a great deal about the seasonal pattern of rainfall and temperature. More detailed climate graphs can help us to see variations within the monthly pattern.

In Figure 6.1 we can see how the mean monthly average occurs between the mean monthly maximum and the mean monthly minimum. (The mean monthly maximum is the average of all the maximum temperatures for each day of the month, and the mean monthly minimum is an average of all the minimum temperatures recorded for that month.) We could also show the absolute maximum and the absolute minimum for that month, although the climate graph would begin to look cluttered. Alternatively, we could use the **absolute values** instead of the **mean monthly values**.

Rainfall is conventionally shown as a bar chart. Different scales are used to show temperature and rainfall. In this example, the temperature scale is shown on the left-hand side and the rainfall is shown on the right-hand side. We can show how weather patterns vary at a particular place by comparing climate graphs of different climate periods, or we can compare climate graphs of different places.

ACTIVITIES

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Mean temperature (°C)	28	27	25	20	15	12	12	14	18	23	25	27	21
Mean maximum temperature (°C)	35	35	32	27	23	19	19	23	27	31	33	35	28
Mean minimum temperature (°C)	21	20	17	12	8	5	4	6	10	15	18	20	13
Rainfall (mm)	44	33	27	10	15	13	7	8	7	18	29	38	249

Table 6.1 Climate data for Alice Springs, Australia

1 **a** Plot the climate data for Alice Springs, as shown in Table 6.1.
b Describe the seasonal variations in
i mean temperature
ii rainfall.
c Calculate the maximum monthly range of temperature and state the maximum range and the months in which it occurs.
d Outline the potential impacts of the climate of Alice Springs for human activities.

Weather maps, satellite images and weather symbols

Synoptic weather maps are used to show the weather that is likely to be experienced at a number of places, whereas a climate graph shows the average conditions for a single location over a year. Most weather maps have a standard set of symbols, although more detailed maps can be produced using a wider range of symbols.

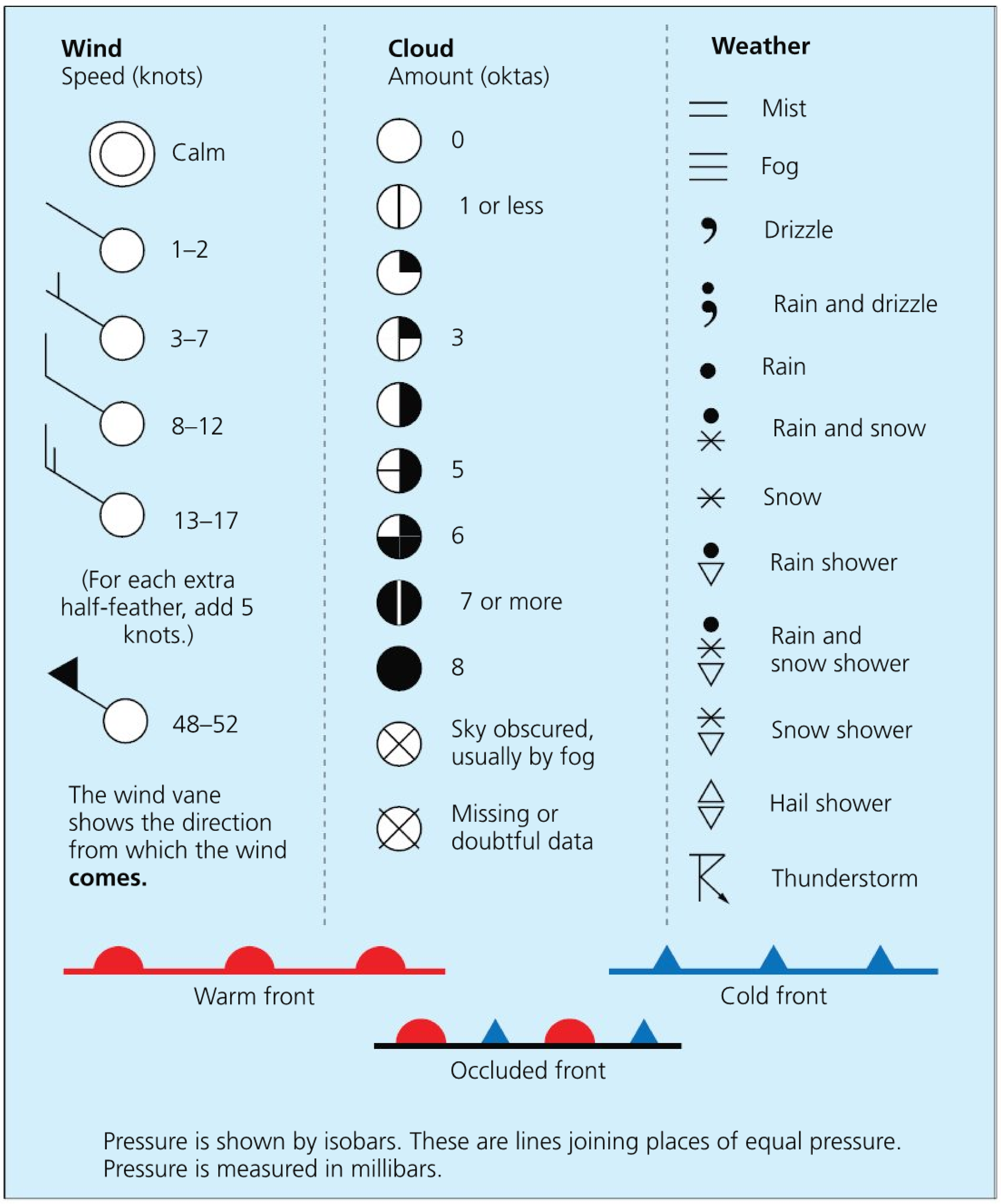


Figure 6.2 Standard weather symbols

Figure 6.3 shows the weather at a particular weather station. It tells us that there is 7/8 cloud cover, the wind is from the south-west and has a speed of 23–27 knots, the temperature is 11 °C and there are rain showers.

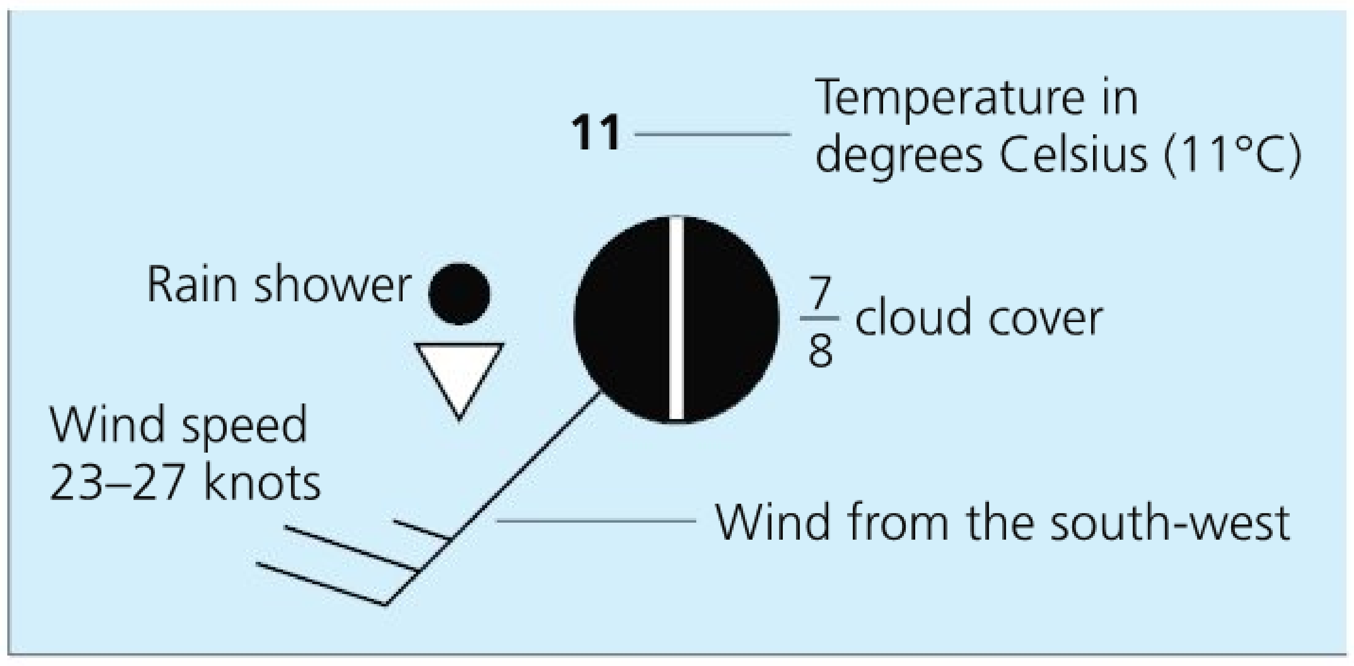


Figure 6.3 Reading weather symbols for a weather station

Large-scale weather maps often show low-pressure systems and high-pressure systems. No two weather maps are exactly the same (though they may be similar) and the pressure systems may be strong or weak. Figure 6.4a is a weather map showing a high-pressure system and Figure 6.4b is a synoptic weather map showing the same system.

Common mistake

Do not draw weather fronts for a high-pressure system – weather fronts are associated with low-pressure systems.

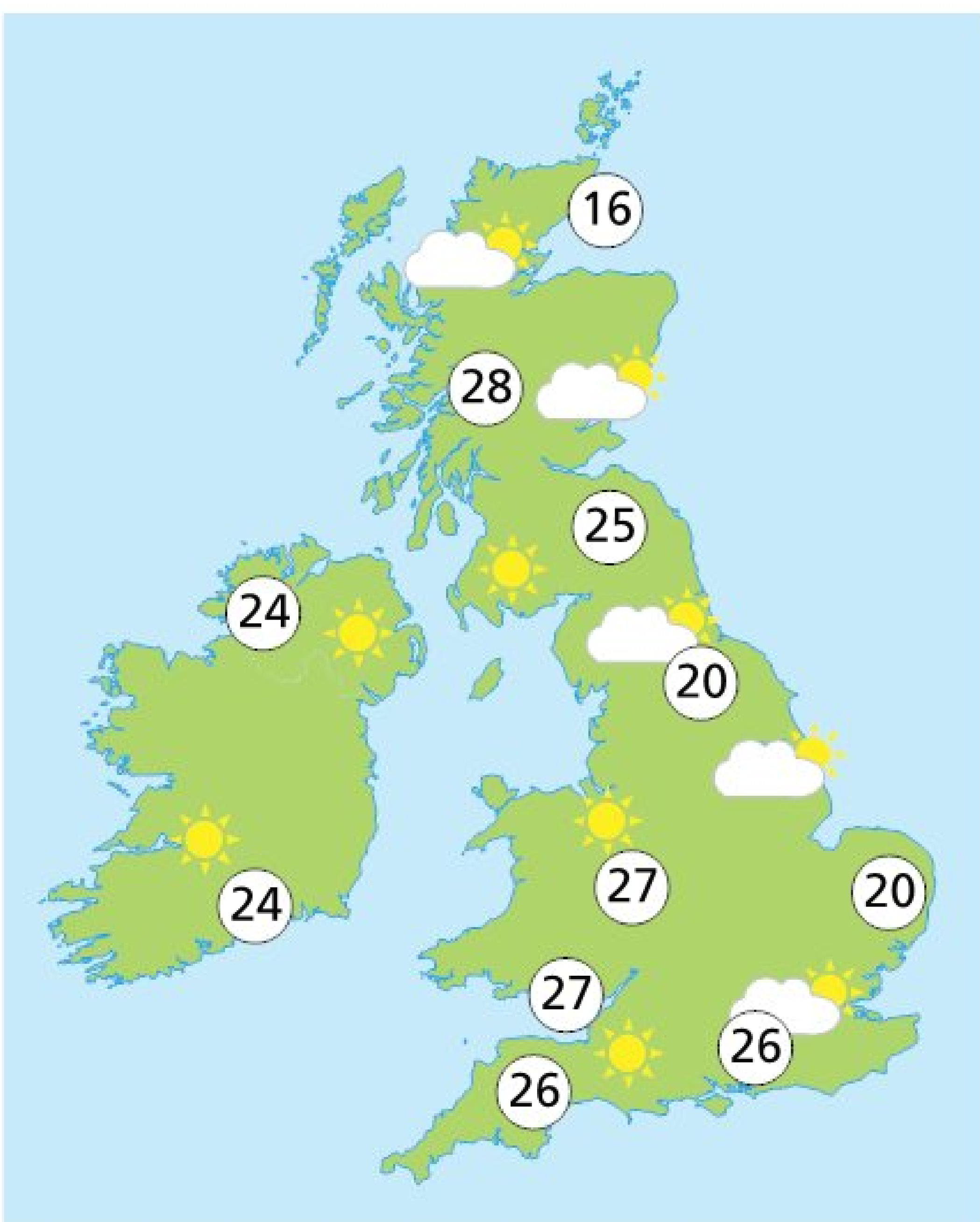


Figure 6.4a A weather map showing a high-pressure system

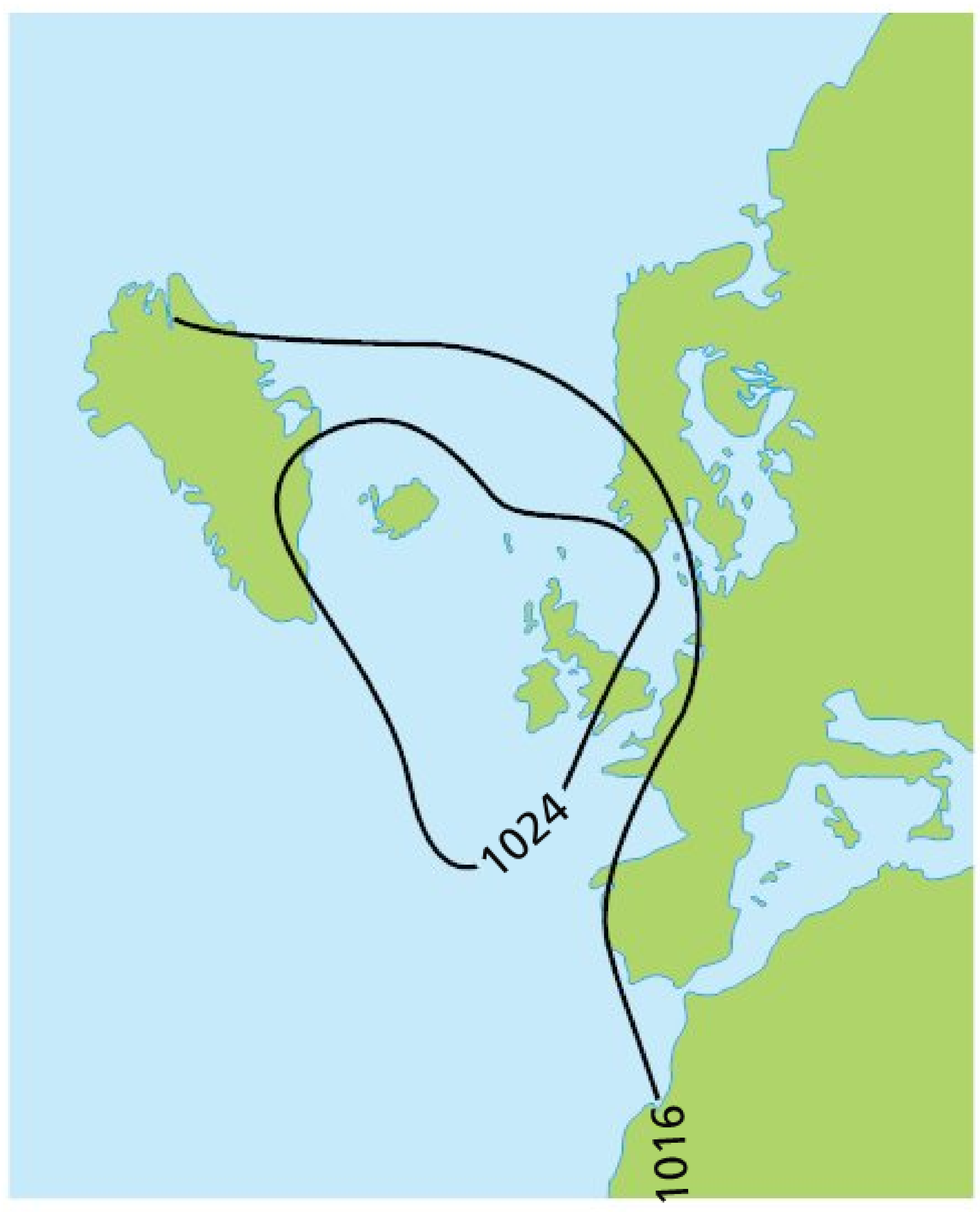


Figure 6.4b A synoptic weather map showing a high-pressure system

Figure 6.5 A satellite image showing a high-pressure system

High-pressure systems produce:

- hot, sunny, dry, calm days in summer
- cold, dry days in winter. Frost and fog are common in winter. Winter nights are cold as the sparse cloud cover allows heat to escape, producing an 'anticyclonic gloom'.

Winds in a high-pressure system blow outwards from the centre of high pressure in a clockwise direction. Owing to the low wind speeds, high-pressure systems can be associated with pollution and poor air quality. This is especially true in large urban areas.

ACTIVITIES

Study the weather map (Figure 6.4a), synoptic weather map (Figure 6.4b) and the weather symbols (Figure 6.2 on page 79).

2 a Describe the location of the clouds in the high-pressure system.
  b State the maximum and minimum temperature found on the map.

3 State the potential problems associated with high-pressure conditions in
  a summer
  b winter.

Figures 6.6a, 6.6b and 6.7 show a low-pressure system over the same area. The image was taken during the spring.

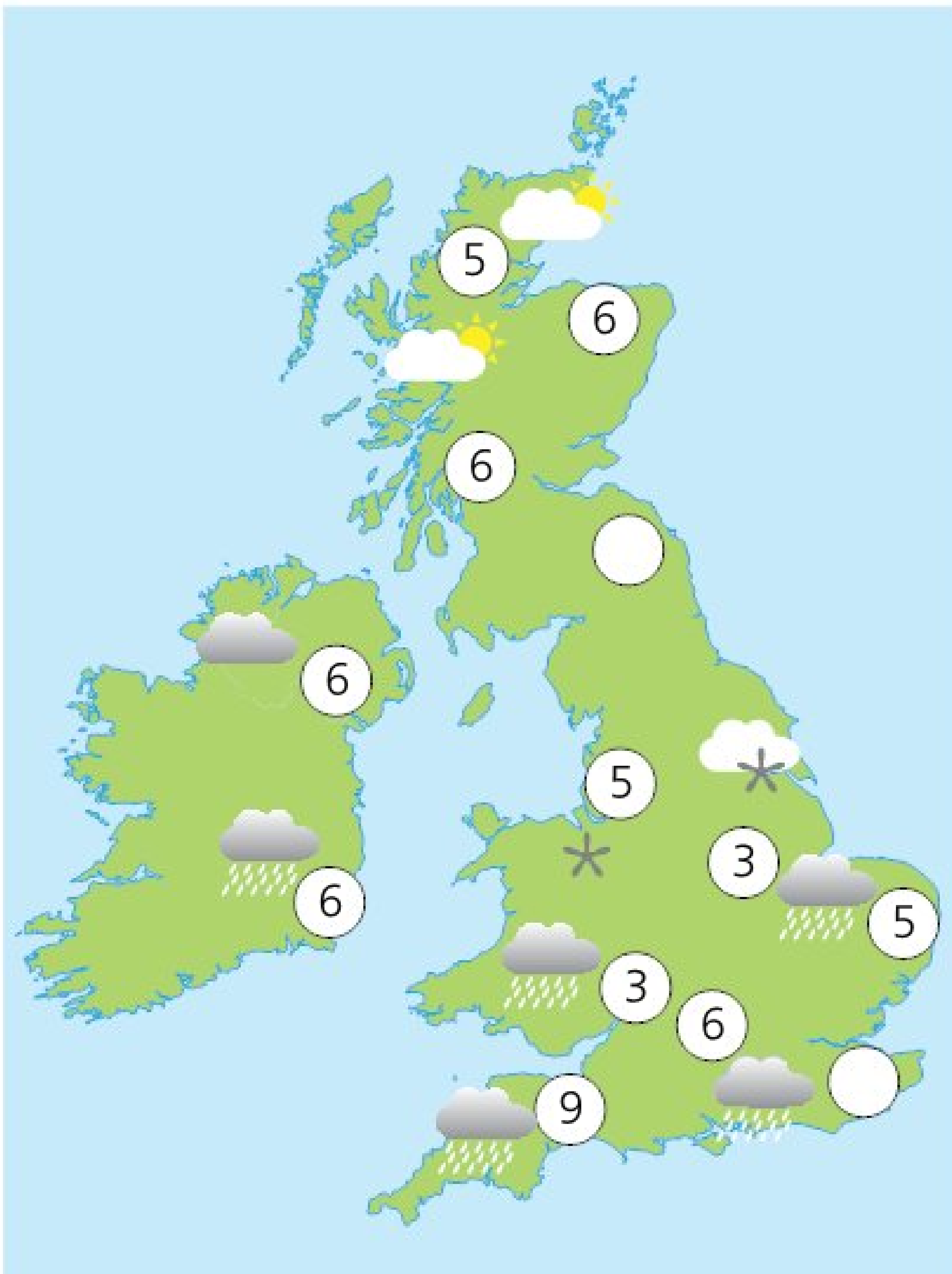


Figure 6.6a A weather map showing a low-pressure system

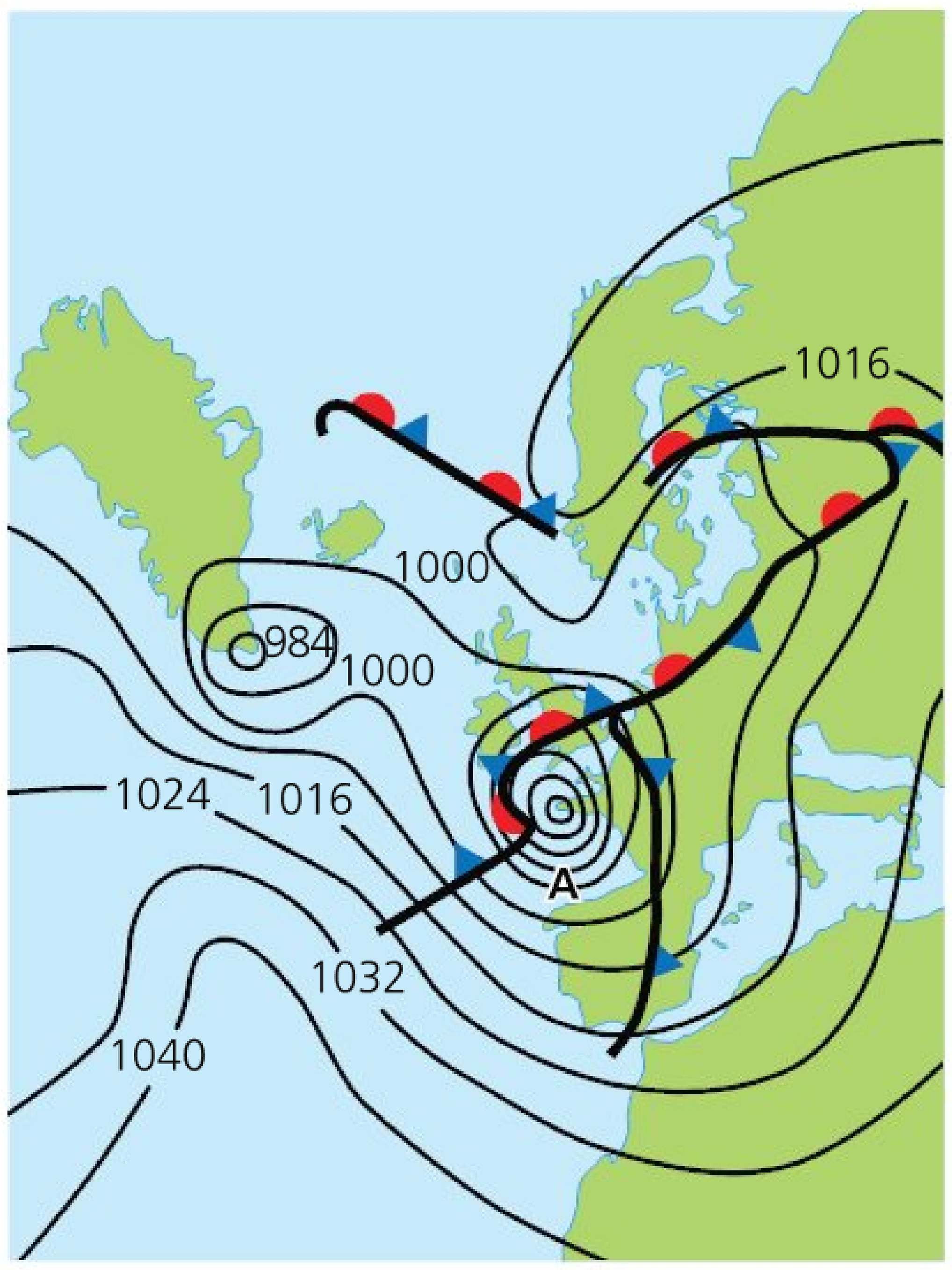


Figure 6.6b A synoptic weather map showing a low-pressure system

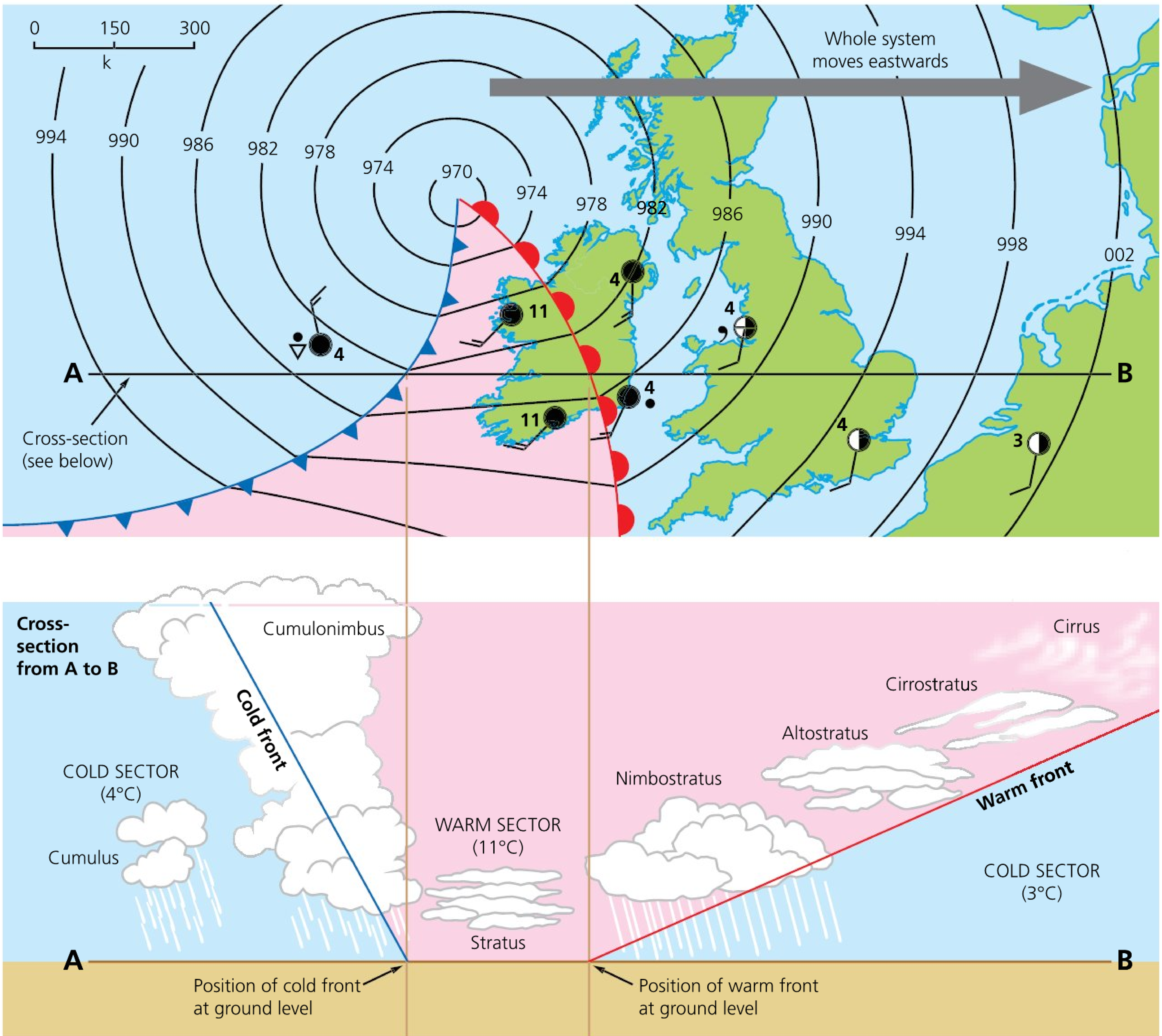
Figure 6.7 A satellite image showing a low-pressure system

Expert tip

In a low-pressure system, the clouds often have a circular pattern to them as they 'swirl' into the centre of low pressure.

A low-pressure system develops when warm air and cold air meet. The warm air, being less dense than the cold air, rises over it. Condensation occurs leading to cloud formation.

Wind speeds in low-pressure systems can be quite high. Winds in a low-pressure system blow anticlockwise and inwards towards the centre of low pressure. The whole system is gradually moving eastwards, and the main weather conditions associated are shown in Figure 6.8.



Weather conditions across the low-pressure system

	After cold front	As cold front passes	Warm sector	As warm front passes over	As warm front approaches	Well before warm front
Cloud type	Fair weather cumulus	Towering cumulonimbus	Dull, low flat stratus	Dense nimbostratus	Lower, thicker altostratus	High altitude cirrus and cirrostratus
Rainfall	Isolated scattered showers	Heavy showers	Mainly dry	Moderate rain	Drizzle	No rain
Temperature (°C)	4°C	4°C	11°C	4°C	4°C	3°C
Wind	North-west, getting weaker	North-west, strong, gusty	South-west, steady, strong	Southerly, strong	Southerly, light, getting stronger	Southerly, light
Air pressure	Rising	Rising	Steady	Falling	1002–998 falling	High (1002), falling

Figure 6.8 The weather associated with the passage of a low-pressure system

Measuring weather

The weather station

A weather station is a place where the elements of weather such as temperature, rainfall, humidity, air pressure, wind direction and velocity, sunshine and cloud cover are measured and recorded as accurately as possible. Weather data can also be monitored using a **Kestrel** (Figure 6.9) or other environmental monitors.

The weather station is placed on an open piece of land and it contains the following instruments: thermometers (ideally kept in a **Stevenson screen** – see Figure 6.10), a rain gauge, barometer, wind vane, anemometer and sunshine recorder. Increasingly, digital instruments are used, and these may provide more reliable and accurate weather data.

Whatever instruments are used, ideally they should have good exposure (that is, they should be sited away from buildings, fences, trees and other obstacles). The flat top of a science block is a favoured location in many schools.

- Thermometers should be placed in the shade. Ideally, they should be in a Stevenson screen or slatted box. If this is not available, they could be hung on a shaded wall or fence.
- Rain gauges should be away from walls, fences and bushes as these affect the amount of rain caught in the rain gauge.
- Wind instruments should be far away from walls, fences and houses as these cause eddies that spoil the reading and make the direction difficult to assess.

It is important that readings are taken at the same time each day.

Figure 6.9 Measuring weather using a 'Kestrel'

Expert tip

Collect weather data at a time that is both convenient and that you can reliably make every day during the course of your investigation.

Stevenson screen

The Stevenson screen is a wooden box standing on four legs at a height of about 120 cm. The screen is built so that the shade temperature of the air can be measured. The sides of the box are slatted to allow free entry of air, and the roof is made of double boarding to prevent the solar energy from reaching the inside of the screen. Insulation is further improved by painting the outside of the screen white so as to reflect much of the solar energy. The screen is usually placed on a grass-covered surface, thereby reducing the radiation of heat from the ground.

Instruments kept inside the Stevenson screen include a maximum–minimum thermometer and a wet- and dry-bulb thermometer (also called a hygrometer).

Instruments kept outside the Stevenson screen include a rain gauge, a wind vane to determine wind direction, and an anemometer to assess wind speed.

Figure 6.10 Stevenson screen

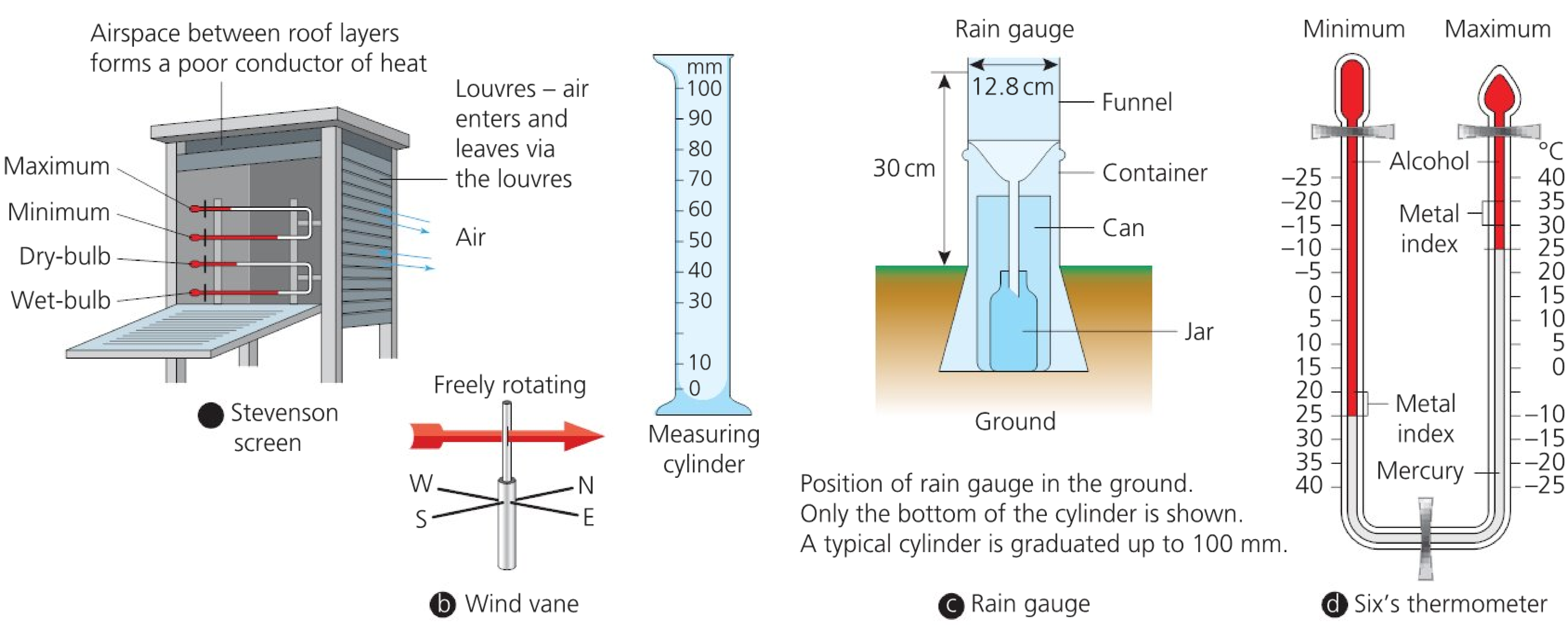


Figure 6.11 Equipment in a weather station

Measuring temperature

Variations in temperature represent responses to differences in insolation, or the amount of energy received from the Sun at different times.

Meteorologists measure the temperature of the air in the shade. Temperature is measured using a thermometer. A continuous temperature reading is given by a thermograph.

- **Maximum thermometer**: when the temperature rises, the mercury in the thermometer expands and pushes the index along the tube. When the temperature falls, the mercury contracts but the index stays where it was pushed to by the mercury. The maximum temperature is obtained by reading the scale at the point of the index. The index is then drawn back to the mercury by a magnet for measuring the next reading.
- **Minimum thermometer** when the temperature falls, the alcohol contracts and its meniscus pulls the index along the tube. When the temperature rises, the alcohol expands. It is read in the same way as the maximum thermometer.
- A **Six's thermometer** (see Figure 6.11d) can be used to measure maximum and minimum temperatures at the same time.

The daily readings of the maximum and minimum thermometers are used to work out the average or mean temperature for one day (this is called the **mean daily temperature**) and the temperature range for one day (the daily or **diurnal temperature range**).

To find the mean daily temperature, the maximum and minimum temperatures for one day are added together and then halved. That is:

$$\frac{\text{maximum temperature} + \text{minimum temperature}}{2} = \text{mean daily temperature}$$

So, for example:

$$\frac{35 + 25}{2} = 30\ °\text{C}$$

The sum of the daily mean temperatures for one month divided by the number of days for that month gives the mean monthly temperature. The sum of the mean monthly temperatures divided by 12 gives the mean annual temperature.

The daily or diurnal temperature range is found by subtracting the minimum temperature from the maximum temperature for any one day. That is:

maximum temperature – minimum temperature = daily or diurnal temperature range

So, for example:

35 – 25 = 10 °C

The highest mean monthly temperature minus the lowest mean monthly temperature gives the mean annual temperature range For example, Lagos has a mean maximum temperature of 27.5 °C (March), and a mean minimum temperature of 24.5 °C (August), which means its annual temperature range is therefore 3.0 °C.

Measuring rainfall

A **rain gauge** is used to measure rainfall. It consists of a cylinder in which there is a collecting can containing a glass or plastic jar and a funnel that fits in the top of the container. The gauge is placed in an open space so that only raindrops enter the funnel of the gauge, and no run-off from trees, buildings or other objects can get into the funnel. The gauge is sunk into the ground so that the top of the funnel is about 30 cm above ground level (Figures 6.11c and 6.12). This is to prevent the solar energy from evaporating any water collected and to ensure no rain splashes up from the ground into the funnel.

Rain falling over the funnel collects in the jar. This is emptied, usually every 24 hours, and measured in a tapered glass measure, graduated in millimetres. The tapered end of the jar enables very small amounts of rain to be measured accurately.

The rainfall recorded for a place, either for a day or for a week, month or year, can be shown on a map. This is done by using lines called **isohyets**

Figure 6.12 The measuring cylinder from a rain gauge

Key definition

Isohyet – a line on a map that joins areas of equal rainfall.

It is important to check the rain gauge every day, preferably at the same time of day, even if there has not been any rainfall. This is because small amounts of dew and other objects, such as leaves, spiders and slugs, may accumulate in the gauge, leading to false readings when it does rain.

Measuring relative humidity

The **absolute humidity** is the actual amount of moisture held by a cubic metre of air and is expressed in $g\,m^{-3}$. By contrast, the **relative humidity** expresses this amount of air relative to the largest amount of air a given temperature can carry. For example, if the air in a classroom was 20 °C and it held 8.5 g of water per m^3, the relative humidity would be 8.5/17 (17 $g\,m^{-3}$ being the maximum amount of water vapour that air of 20 °C can hold). Hence the relative humidity would be 50%, that is, the air is only holding half of the maximum water vapour it could hold. If the amount of water vapour in the air remains constant, the relative humidity decreases (or increases) as the temperature rises (or falls). A normal diurnal range may be from 95% around dawn to about 60% in the afternoon. Values below 40% are unusual, and only rarely do they fall below 10% in the UK. In fact, values of 10% are generally common over deserts during the day.

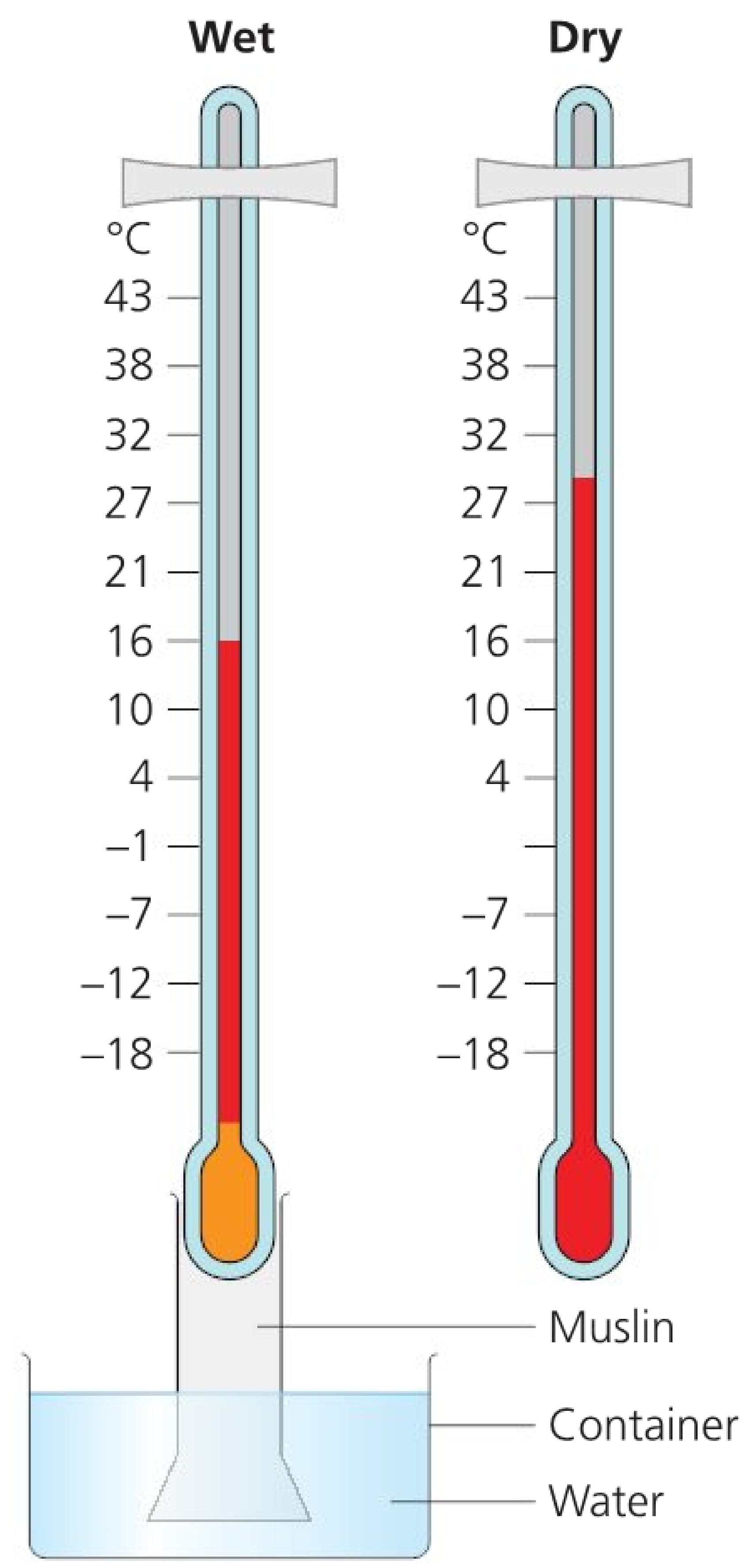


Figure 6.13 Wet- and dry-bulb thermometer

Key definitions

Absolute humidity – the actual amount of moisture held by a cubic metre of air.

Relative humidity – a measure of the amount of water vapour in the air compared to the maximum that could be contained by the air at the same temperature when the air is saturated.

Wet- and dry-bulb thermometers are used to measure relative humidity. The dry-bulb is a glass thermometer which records the actual air temperature. The wet-bulb is a similar thermometer, but with the bulb enclosed in a muslin bag which is dipped into a bottle of water (Figure 6.13). This thermometer measures the wet-bulb temperature which, unless the relative humidity is close to 100%, is generally lower than the dry-bulb temperature.

The difference between the dry-bulb and wet-bulb temperatures is called the wet-bulb depression. It is this, along with the dry-bulb temperature, that enables meteorologists to calculate the **dew point**, temperature and relative humidity using suitable tables (Table 6.2).

Key definition

Dew point – the temperature at which relative humidity is 100%.

Dry-bulb temperature	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
50	97	94	92	89	87	84	82	79	77	74	72	70	68	66	63	61
49	97	94	92	89	86	84	81	79	77	74	72	70	67	65	63	61
48	97	94	92	89	86	84	81	79	76	74	71	69	67	65	62	60
47	97	94	92	89	86	83	81	78	76	73	71	69	66	64	62	60
46	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	59
45	97	94	91	88	86	83	80	78	75	73	70	68	66	63	61	59
44	97	94	91	88	86	83	80	78	75	72	70	68	65	63	61	58
43	97	94	91	88	85	83	80	77	75	72	70	67	65	62	60	58
42	97	94	91	88	85	82	80	77	74	72	69	67	64	62	59	57
41	97	94	91	88	85	82	79	77	74	71	69	66	64	61	59	56
40	97	94	91	88	85	82	79	76	73	71	68	66	63	61	58	56
39	97	94	91	87	84	82	79	76	73	70	68	65	63	60	58	55
38	97	94	90	87	84	81	78	75	73	70	67	65	62	59	57	54
37	97	93	90	87	84	81	78	75	72	69	67	64	61	59	56	54
36	97	93	90	87	84	81	78	75	72	69	66	63	61	58	55	53

Dry-bulb temperature	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
35	97	93	90	87	83	80	77	74	71	68	65	63	60	57	55	52
34	96	93	90	86	83	80	77	74	71	68	65	62	59	56	54	51
33	96	93	89	86	83	80	76	73	70	67	64	61	58	56	53	50
32	96	93	89	86	83	79	76	73	70	67	64	61	58	55	52	49
31	96	93	89	86	82	79	75	72	69	66	63	60	57	54	51	48
30	96	93	89	85	82	78	75	72	68	65	62	59	56	53	50	47
29	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	46
28	96	92	88	85	81	77	74	70	67	64	60	57	54	51	48	45
27	96	92	88	84	81	77	73	70	66	63	60	56	53	50	47	44
26	96	92	88	84	80	76	73	69	66	62	59	55	52	49	46	42
25	96	92	88	84	80	76	72	68	65	61	58	54	51	47	44	41
24	96	91	87	83	79	75	71	68	64	60	57	53	50	46	43	39
23	96	91	87	83	79	75	71	67	63	59	56	52	48	45	41	38
22	95	91	87	82	78	74	70	66	62	58	54	51	47	43	40	36
21	95	91	86	82	78	73	69	65	61	57	53	49	45	42	38	35
20	95	91	86	81	77	73	68	64	60	56	52	48	44	40	36	33
19	95	90	86	81	76	72	67	63	59	55	50	46	42	38	34	31
18	95	90	85	80	76	71	66	62	58	53	49	45	41	36	32	29
17	95	90	85	80	75	70	65	61	56	52	47	43	39	34	30	26
16	95	89	84	79	74	69	64	60	55	50	46	41	37	32	28	24
15	94	89	84	78	73	68	63	58	53	49	44	39	35	30	26	21
14	94	89	83	78	72	67	62	57	52	47	42	37	32	28	23	18
13	94	88	83	77	71	66	61	55	50	45	40	35	30	25	20	16
12	94	88	82	76	70	65	59	54	48	43	38	32	27	22	17	12
11	94	87	81	75	69	63	58	52	46	41	35	30	25	19	14	9
10	93	87	81	74	68	62	56	50	44	38	33	27	22	16	11	5
9	93	86	80	73	67	61	54	48	42	36	30	24	18	13	7	2
8	93	86	79	72	66	59	52	46	40	33	27	21	15	9	3	
7	93	85	78	71	64	57	50	44	37	31	24	18	11	5		
6	92	85	77	70	63	55	48	41	34	28	21	14				
5	92	84	76	69	61	53	46	39	31	24						
4	92	83	75	67	59	51	44	36								
3	91	83	74	66	57	49										
2	91	82	73	64												
1	90	81														

THERMOMETER HYGROMETER

Fill the reservoir and ensure the wick is wet. Note the dry-bulb reading (left-hand column). Subtract the wet-bulb reading from the dry-bulb reading to find the wet-bulb depression. Note the difference along the top line. Follow this column down until level with the dry-bulb reading for the percentage humidity. Best results will be achieved when the instrument is sited in slightly moving air (approx. 1 to 1.5 m s).

Table 6.2 Wet- and dry-bulb differences and relative humidity

Measuring air pressure, wind speed and direction

Because air has weight, it exerts a pressure on the Earth's surface. At sea level the pressure is about 1.013 kg cm^{-3}. Pressure varies with temperature and altitude, and the instrument that measures pressure is called a **barometer** (Figure 6.14). Air pressure is usually measured in millibars. Mean global air pressure is about 1 013 mb.

A **mercury barometer** is a hollow tube from which the air is extracted before the open end is placed in a basin of mercury. Mercury is forced up the tube by the pressure of the atmosphere on the mercury in the basin. When the pressure

ACTIVITIES

4 a Define the terms 'humidity', 'absolute humidity' and 'relative humidity'.

b Why does the relative humidity of air rise as its temperature drops, and decrease as the temperature of the air rises?

of the mercury in the tube balances the pressure of the air on the exposed mercury, the mercury in the tube stops rising. The height of the column of mercury changes as air pressure changes: it rises when air pressure increases and falls when air pressure decreases.

An **aneroid barometer** is a vacuum chamber in the form of a small metal cylinder. Inside, a strong metal spring prevents the chamber from collapsing. The spring contracts and expands with changes in atmospheric pressure. These changes are magnified by a series of levers and the movements are conveyed to a pointer which moves across a calibrated scale.

A **barograph** is a tracing from an aneroid barometer which records continuously for one week. Changes in pressure are recorded by a flexible arm which traces an ink line on a rotating paper-covered drum. The paper is divided by vertical lines at two-hour intervals.

The **atmospheric pressure** is recorded at numerous weather stations for a region and these are plotted on a map of the region. First though, the pressures are 'reduced' to sea level – that is, they are adjusted to what they would be if the stations were at sea level. The pressures are plotted on a map. Lines are then drawn through points where pressure is the same. These lines are called **isobars**

The **wind vane** is used to indicate wind direction. It consists of a horizontal rotating arm pivoted on a vertical shaft. The rotating arm has a tail at one end and a pointer at the other. When the wind blows, the arm swings until the pointer faces the wind. The directions north, east, south and west are marked on the arms which are rigidly fixed to the shaft.

The speed of the wind is measured by an **anemometer** (Figures 6.15 and 6.16), which consists of three or four metal cups fixed to metal arms that rotate freely on a vertical shaft. When there is a wind, the cups rotate. The stronger the wind, the faster the rotation. The number of rotations is recorded on a meter to give the speed of the wind in $\mathrm{km\,hr^{-1}}$

The wind vane and anemometer are placed well away from any buildings or trees that may interfere with the free movement of air. Buildings may channel air through narrow passages between two buildings or decrease the flow of air by blocking its path. Trees have a similar effect.

Winds are shown by arrows on a weather map. The shaft of the arrow indicates wind direction and the feathers on the shaft indicate wind velocity. The tip of the arrow, at the opposite end from the feathers, points to the direction in which the wind is blowing from.

Force	Description	Wind speed (mph)	Typical effect overland
0	Calm	Less than 1	Smoke rises vertically
1–3	Light	1–12	Smoke drifts or leaves rustle
4	Moderate	13–18	Small branches move
5	Fresh	19–24	Small trees in leaf begin to sway
6–7	Strong	25–38	Large branches or whole trees in motion
8	Gale	39–46	Twigs break off trees
9	Severe gale	47–54	Chimney pots and tiles removed
10–11	Storm	55–72	Trees uprooted, widespread damage
12	Hurricane*	More than 73	Devastation

(* also known as a tropical cyclone, typhoon)

Table 6.3 Measuring wind speed – the Beaufort scale

Figure 6.14 A simple barometer

Figure 6.15 An anemometer

Figure 6.16 A digital anemometer

Wind direction for a specific place can be shown on a **wind rose** (Figure 6.17). It is made up of a circle from which rectangles radiate. The directions of the rectangles represent the points of the compass. The lengths of the rectangles are determined by the number of days/times the wind blows from that direction. The number of days/times (hours) when there is no wind is recorded in the centre of the rose.

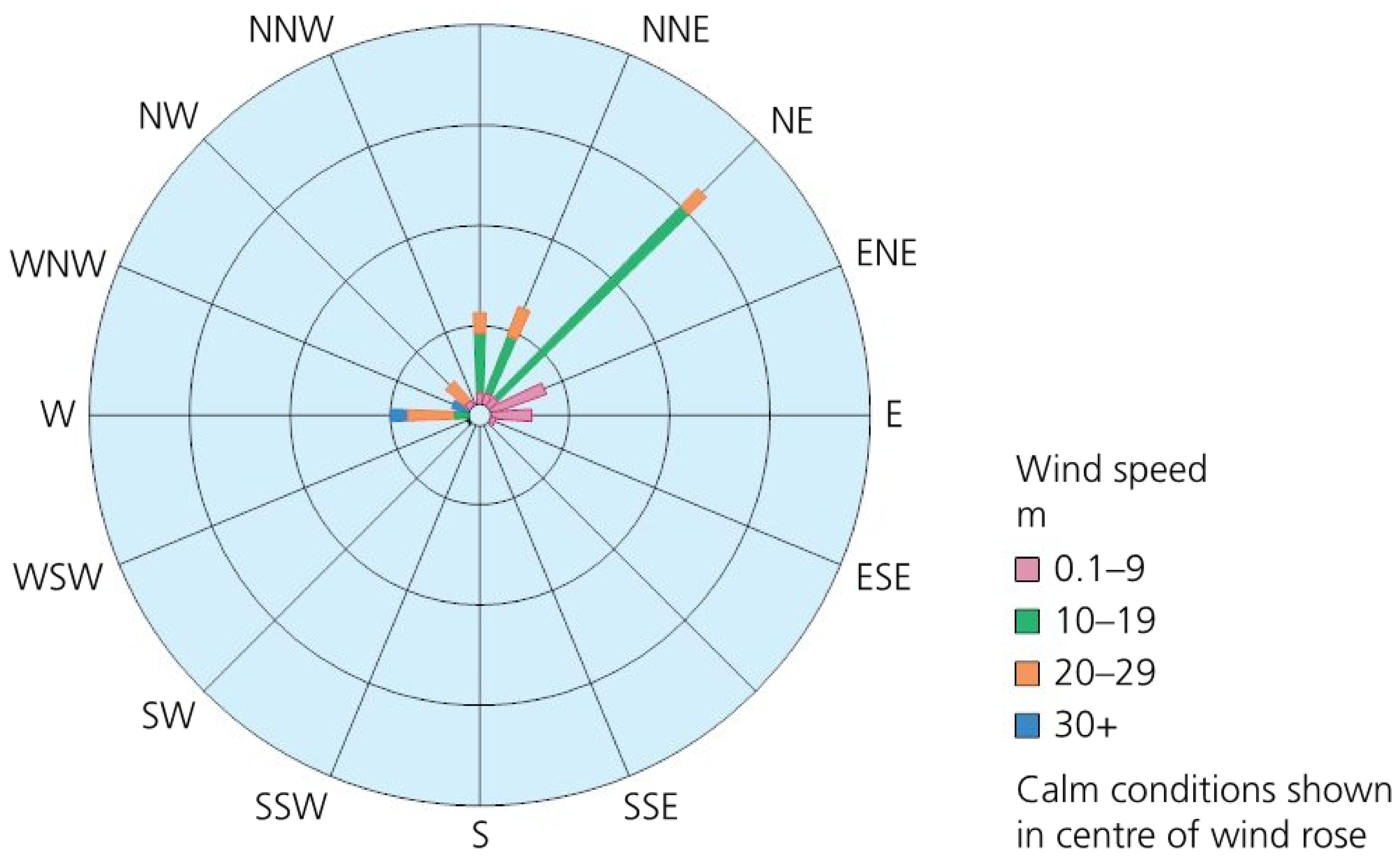


Figure 6.17 A wind rose

Measuring sunshine hours

The number of hours and minutes of sunshine received at a place can be measured and recorded by a **sunshine recorder**. This is a glass sphere partly surrounded by a metal frame (Figure 6.18). A strip of special card, divided up into hours and minutes, is placed below the sphere. When the Sun shines, the sphere focuses the Sun's rays on the card. As the Sun moves, the rays burn a trace on the card. At the end of the day, the card is removed and replaced. The length of the trace represents the amount of sunshine that the location received.

Clouds

The ten main types of cloud can be separated into three broad categories according to the height of their base above the ground: high clouds, medium clouds and low clouds (Figure 6.19a).

High clouds are usually composed solely of ice crystals and have a base between 5500 and 14000 m. These are described as:

- **cirrus**: white filaments
- **cirrocumulus**: small rippled broken clouds
- **cirrostratus**: a transparent, slightly semi-circular high cloud.

Medium clouds are usually composed of water droplets or a mixture of water droplets and ice crystals, and have a base between 2000 and 7000 m:

- **altocumulus**: layered, rippled elements, generally white with some shading
- **altostratus**: a thin layer, grey, allows the Sun to appear as if through ground glass.

Low clouds are usually composed of water droplets, although cumulonimbus clouds include ice crystals, and have a base below 2000 m:

- **stratocumulus**: layered, a series of rounded rolls, generally white with some shading
- **stratus**: layered, uniform base, grey
- **nimbostratus**: a thick layer with a low base, dark, and rain or snow may fall from it

ACTIVITIES

5 a Describe and explain the main characteristics of a Stevenson screen.
  b What information does a Six's thermometer show?
  c Why are weather readings taken at the same time each day?
  d Where is the best place to locate a rain gauge? Briefly explain why.
  e How are wind speed and wind direction measured?

Figure 6.18 A Campbell–Stokes sunshine recorder

- **cumulus**: individual cells, vertical rolls or towers with a flat base
- **cumulonimbus**: large cauliflower-shaped towers, often with 'anvil tops', and sometimes giving thunderstorms or showers of rain or snow.

Cloud cover is measured in oktas (eights). This is made by a visual assessment of how much of the sky is covered by cloud. For example, in Figure 6.19b approximately 5/8 of the sky is covered by cloud, where as in Figure 6.19d, the whole sky is covered in cloud, so has 8/8 cloud cover.

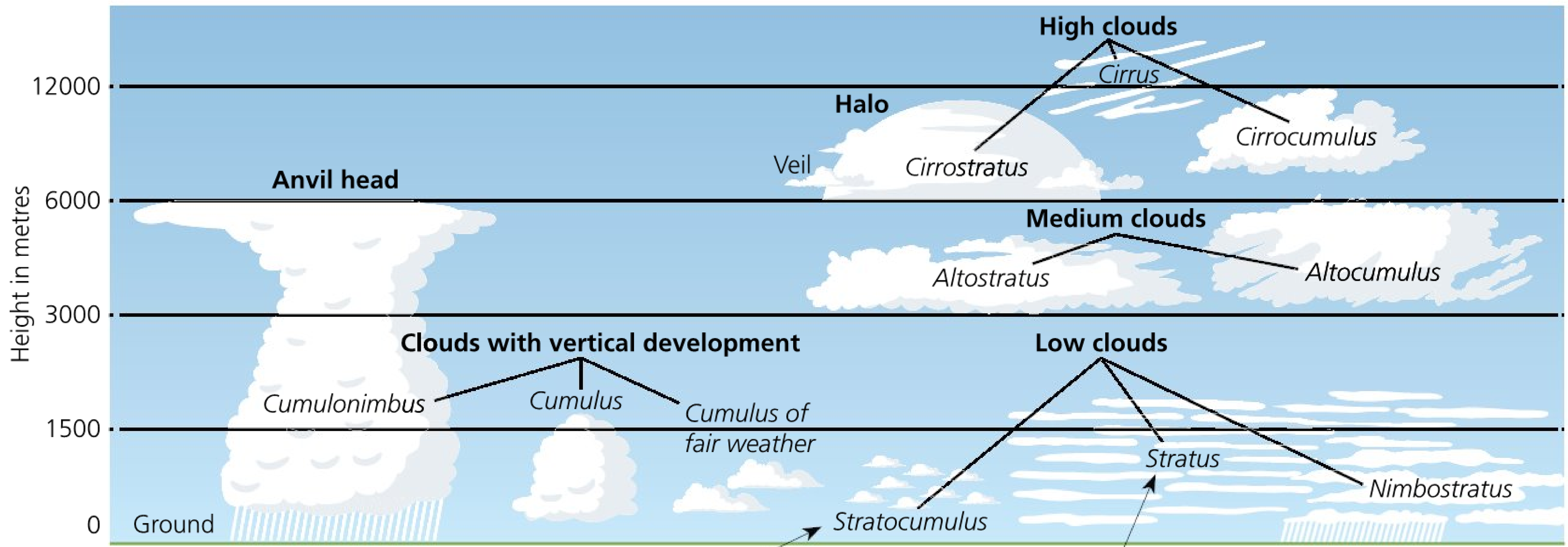


Figure 6.19a Cloud types

Figure 6.19b Cumulus and strato-cumulus clouds

Figure 6.19c Cumulonimbus clouds

Figure 6.19d Stratus cloud formed by orographic uplift

ACTIVITIES

6 The results recorded by a school in Victoria, in Australia, are shown in Tables 6.4 and 6.5. The data for the first week of August are plotted in Figure 6.20 on page 90.

Date	Day	Temperature Maximum (°C)	Temperature Minimum (°C)	Rainfall (mm)	Wind direction	Wind speed (km hr^{-1})	Air pressure (mb)
1 August	W	14.2	9.7	4.0	N	22	1 006
2	Th	13.4	11.5	0	N	37	1 004
3	F	9.9	8.1	0	WNW	33	1 011
4	S	11.5	7.2	0	WNW	31	1 016
5	S	11.6	8.2	0	W	28	1 019
6	M	12.7	9.5	20.2	W	20	1 023
7	T	14.5	9.2	0	N	30	1 019

Table 6.4 Daily weather observations at Frankston, Victoria (Australia)

Date	Day	Temperature		Rainfall (mm)	Wind direction	Wind speed (km hr^{-1})	Air pressure (mb)
		Maximum (°C)	Minimum (°C)				
1 February	F	25.6	11.7	6.8	SSE	15	1 020
2	S	25.7	16.9	0	NNW	9	1 016
3	S	27.6	17.9	0	SE	9	1 016
4	M	29.1	19.9	0	ENE	11	1 013
5	T	23.2	19.7	0	SW	13	1 012
6	W	23.1	19.2	0	SW	19	1 004
7	Th	17.9	15.7	8.4	SW	19	1 005

Table 6.5 Daily weather observations at Frankston, Victoria (Australia)

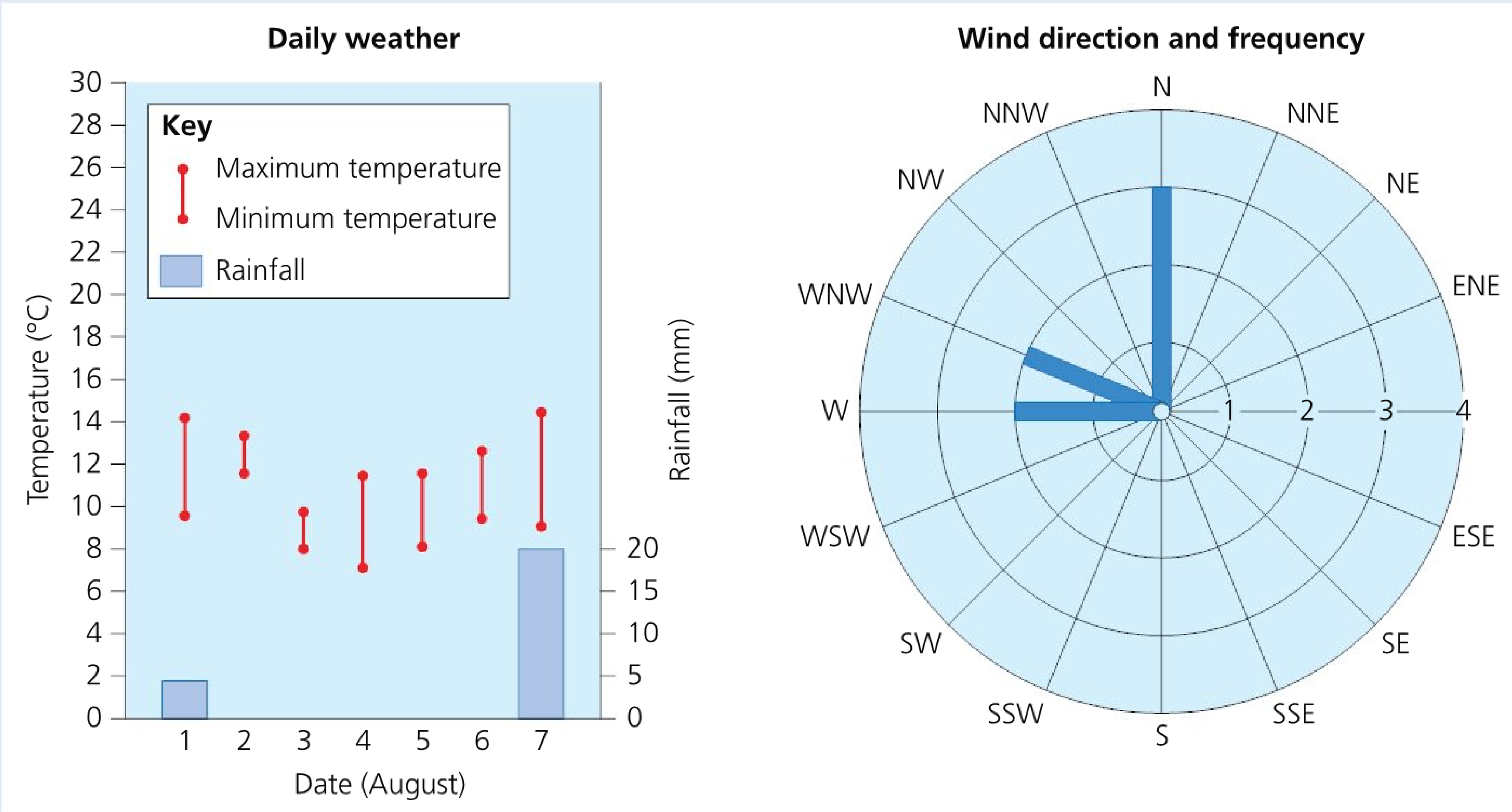


Figure 6.20 Daily weather, wind direction and frequency at Frankston, Victoria (Australia)

- **a** Plot the data for February using the same methods as in Figure 6.20.
- **b** State the maximum and minimum temperature of the seven-day period in February.
- **c** Deduce the mean minimum temperature and the mean maximum temperature for the seven days.
- **d** How much rain fell during the seven days?
- **e** Compare the weather in February with that in August.

Microclimates

Urban microclimates

The contrast between urban and rural areas is greatest under calm high-pressure conditions. The typical heat profile of an urban **heat island** shows a maximum at the city centre, a plateau across the suburbs and a temperature cliff between the suburban and rural areas. Small-scale variations within the urban heat island occur with the distribution of industries, open spaces, rivers, canals, and so on.

The nature of urban climates is changing. With the decline in coal as a source of energy, there is less sulphur dioxide pollution and so fewer hygroscopic nuclei from burning coal, resulting in less fog. However, an increase in cloud cover has occurred for several reasons:

- greater heating of the air (rising air, hence condensation)
- an increase in other pollutants, especially from vehicles – for example, PM 10s and PM 2.5s (particulate matter of less than 10 and 2.5 micrometres respectively)
- frictional and turbulent effects on airflow
- changes in moisture.

Urban areas have many different types of land use such as residential, industrial, retail, recreational, open space and energy production, and these have different impacts on the storage and release of heat during the day and night. Urban areas also vary in their **albedo** (Figure 6.21).

Key definition

Albedo – the reflectivity of a surface.

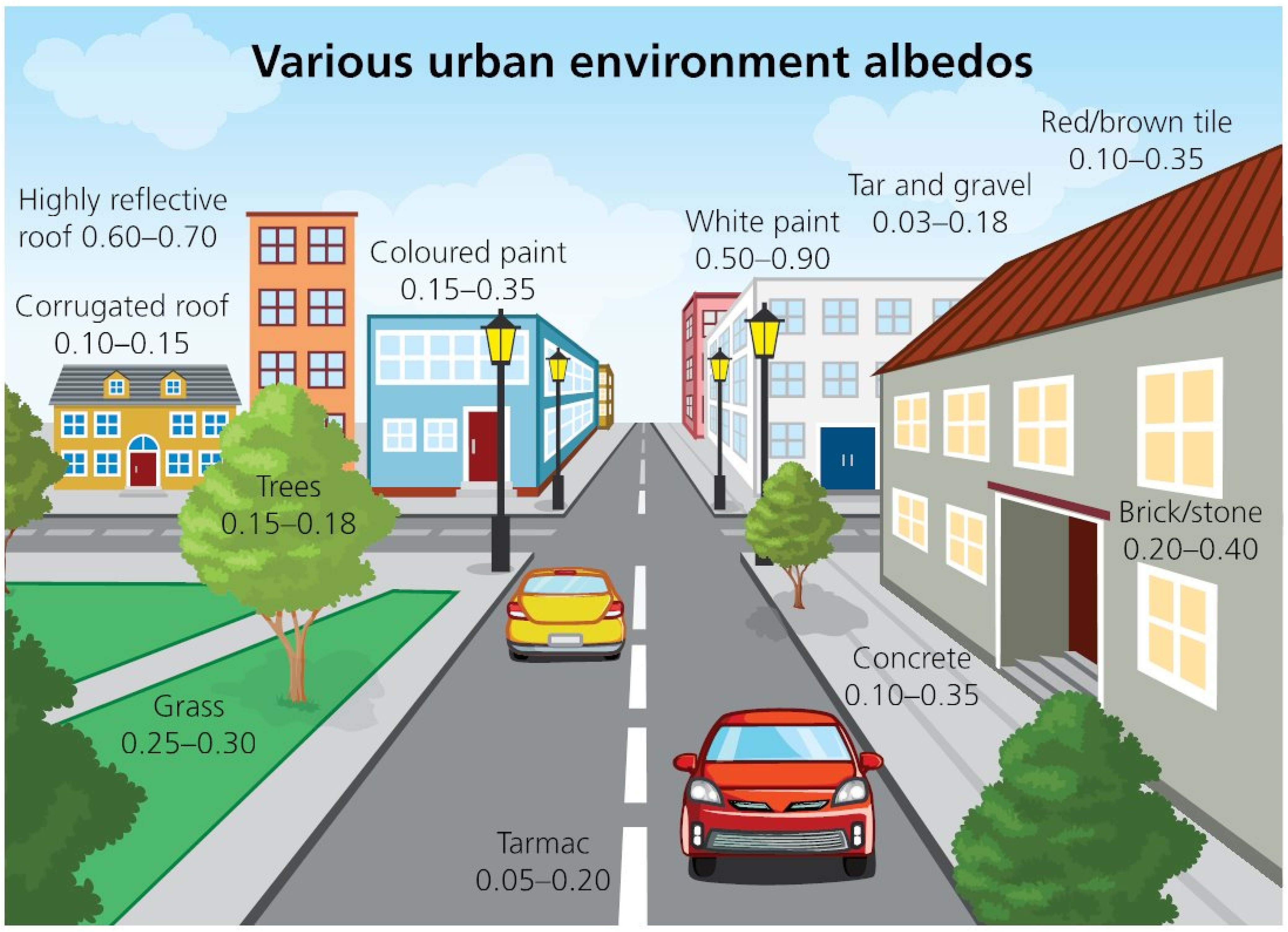


Figure 6.21 Variations in albedo in urban areas

■ ACTIVITIES

Figure 6.22 Variations in minimum temperatures of a school during a winter high-pressure system

7 **a** Describe the variations in minimum temperatures as shown in Figure 6.22.

b Suggest reasons to explain the variations in temperature shown in Figure 6.22.

Expert tip

High pressure generally produces clear and calm conditions, whereas low pressure frequently produces wet and windy conditions.

■ ACTIVITIES

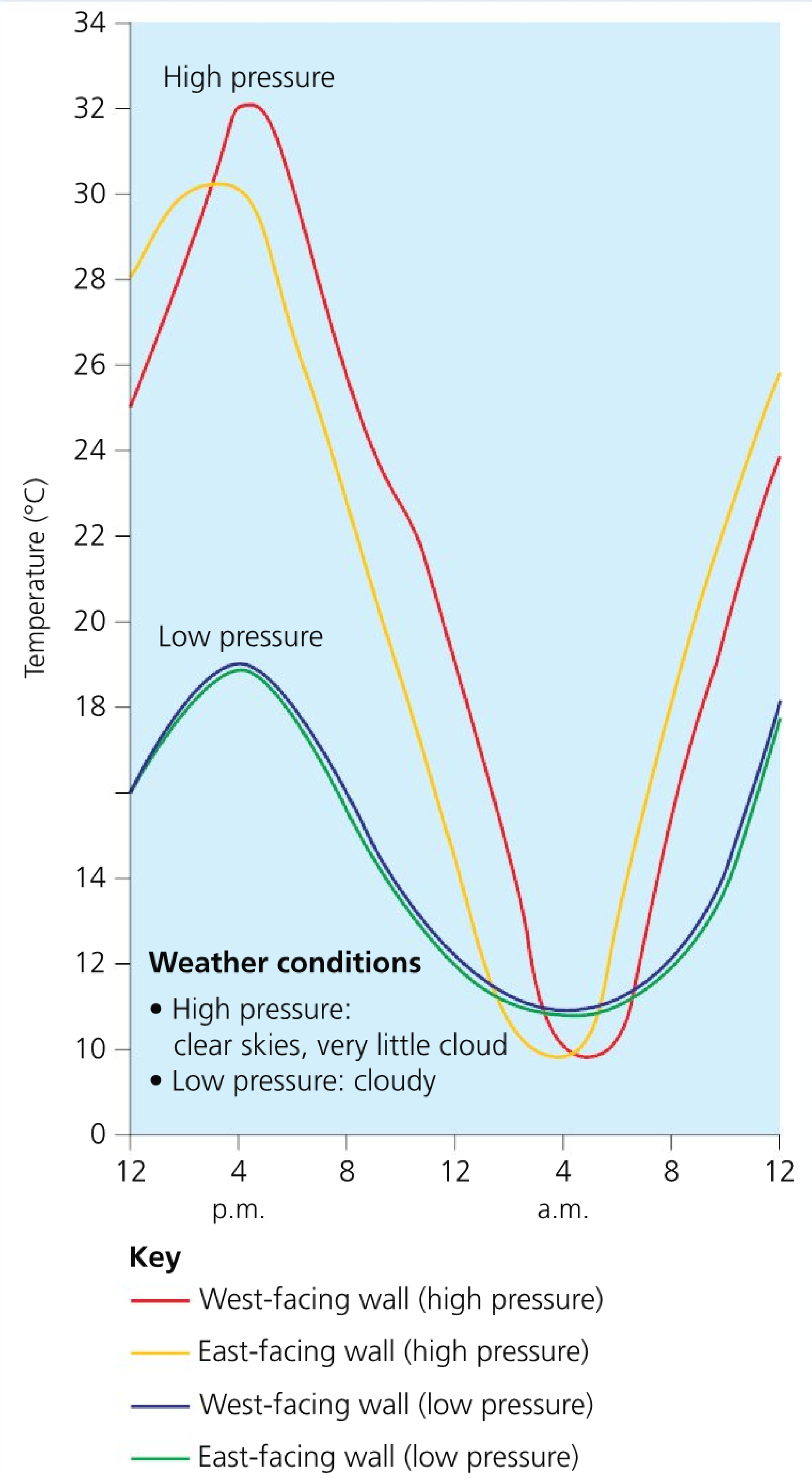


Figure 6.23 Diurnal (daytime and night-time) variations in temperature on east- and west-facing walls during high- and low-pressure systems

8 **a** Describe the variations in temperature between the west-facing and east-facing walls

i during high pressure

ii during low pressure.

b Suggest reasons for the contrasting patterns in high pressure and low pressure.

Forest microclimates

The microclimate of a forest varies compared to its surrounding areas in terms of temperature, rainfall, wind speed and light over a relatively short distance.

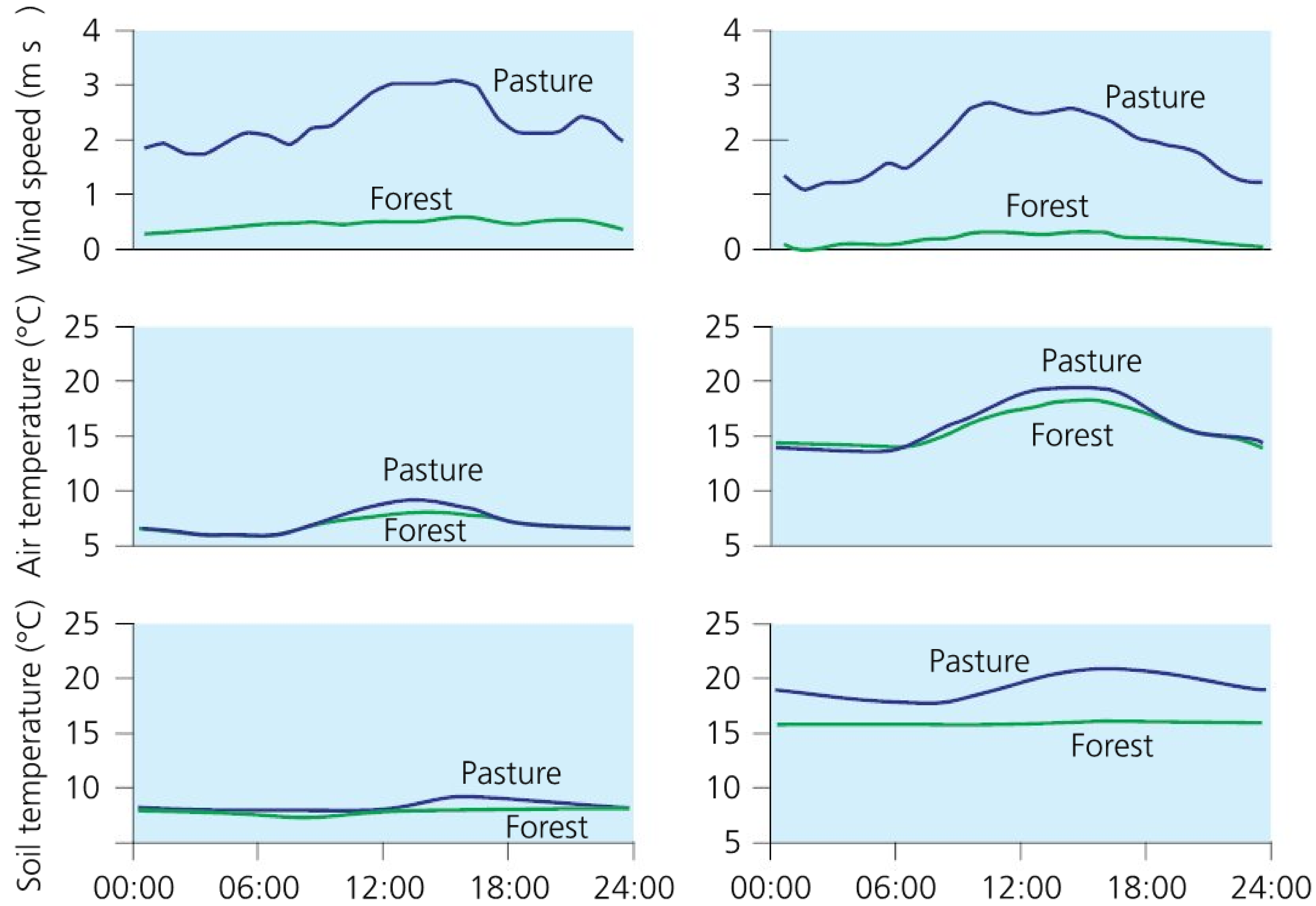


Figure 6.24 Seasonal variations in microclimate between open farmland and forest (winter left and summer right)

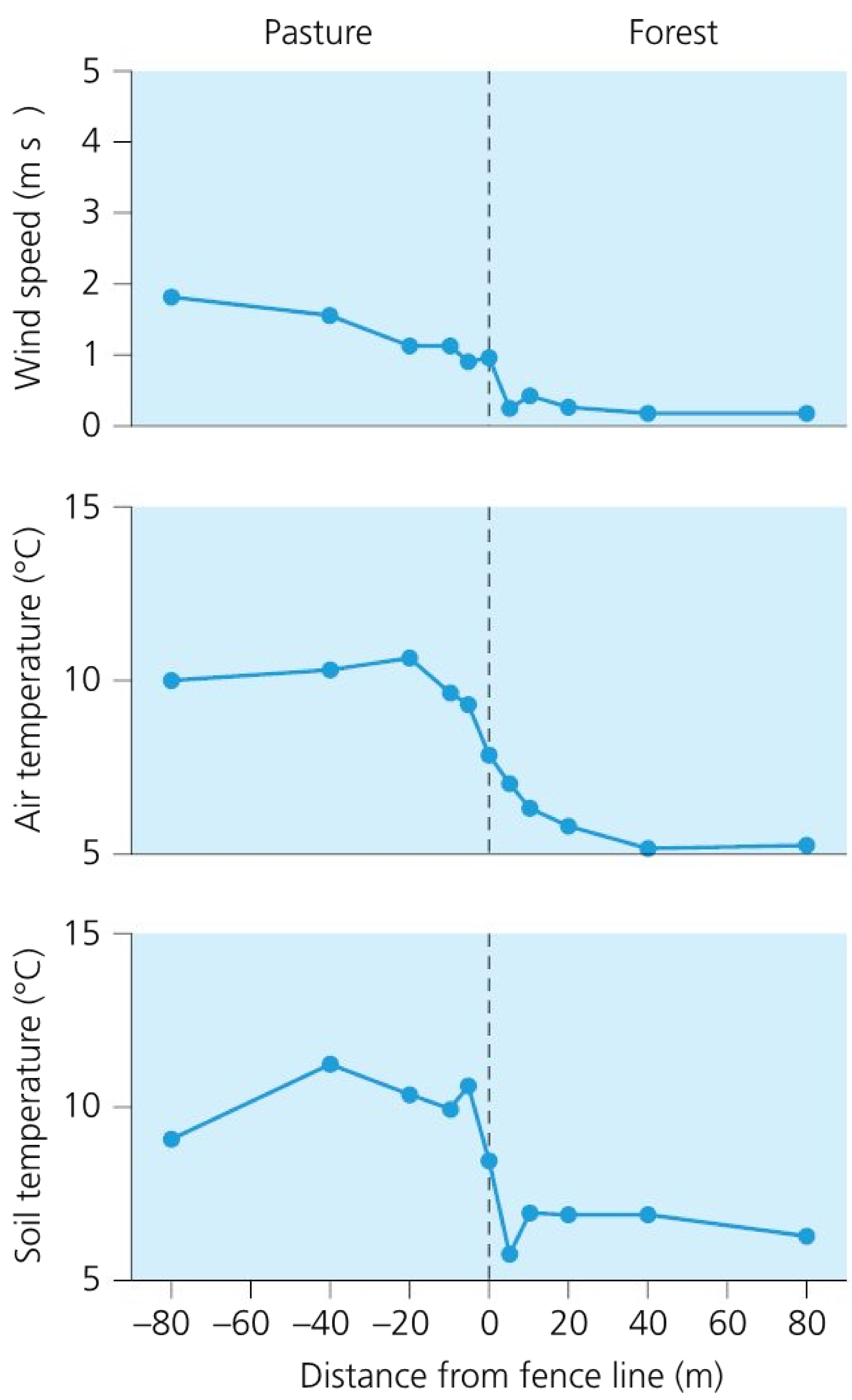


Figure 6.25 Profiles of microclimate variables along a 160 m transect during high-pressure conditions

The near-floor environment of the forest is very much shadier, much less windy, and fluctuates less markedly through the day in temperature and moisture than in the open. The forest is cooler and more moist during the day and, to a lesser extent, warmer and drier at night. These characteristics are well known and quite frequent to both broad-leafed and coniferous forests.

ACTIVITIES

9 **a** Outline the main variations in the microclimates of the forest and the pastureland in
   i winter
   ii summer.

b Describe the variations in wind speed, air temperature and soil temperature along the transect shown in Figure 6.25.

Air pollution

Lichens and air pollution

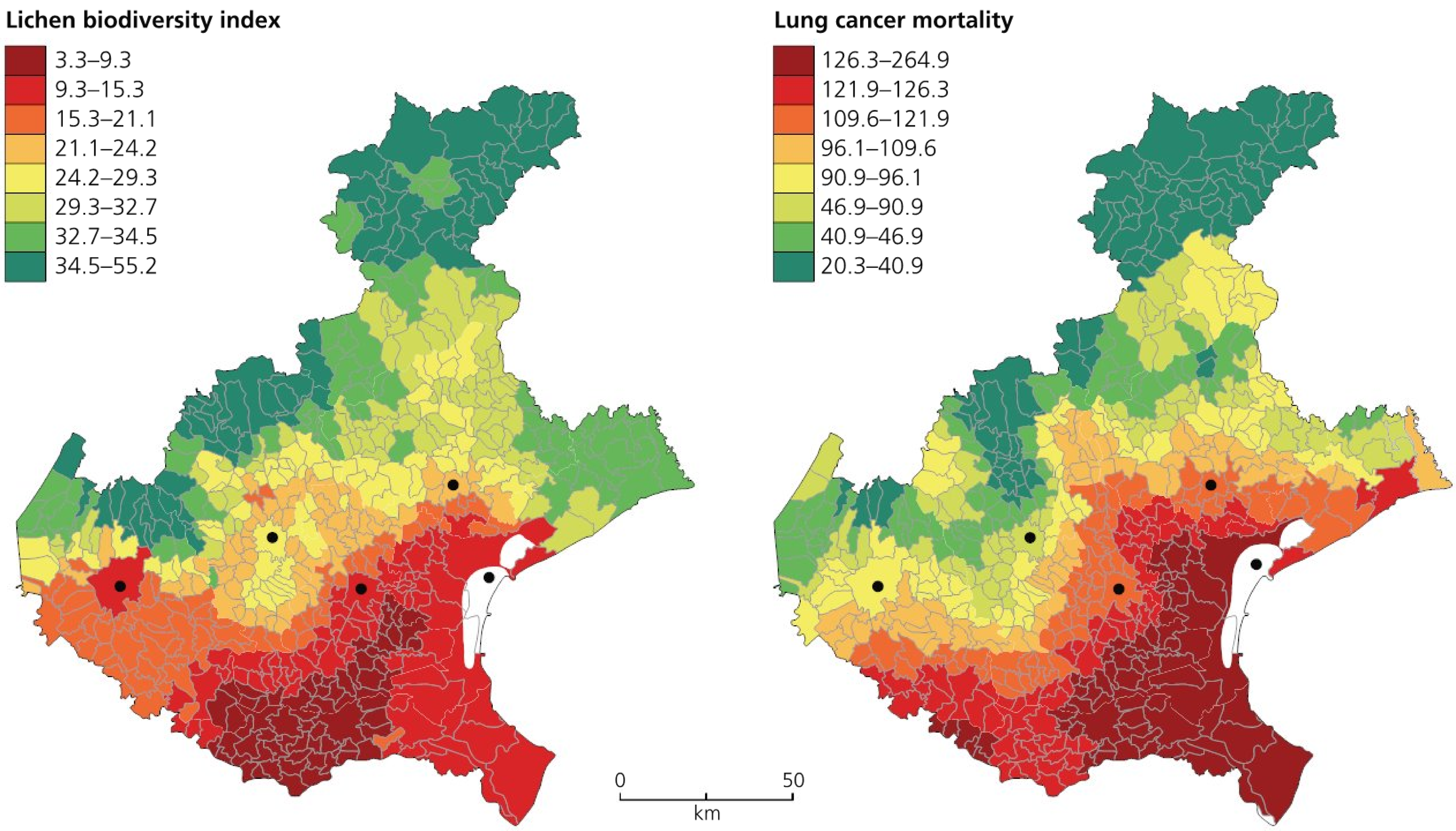
Lichens are mutualistic associations of a fungus and an alga. They are very sensitive to sulphur dioxide pollution in the air. After industrialisation, many lichen species became extinct in large areas (for example, beard moss *Usnea articulate*). This is mainly due to sulphur dioxide pollution, but loss of habitat can also lead to reductions in some species. During the early and mid-twentieth century, air pollution levels in many high-income countries (HICs) were much greater than they are today. However, the air quality is declining today in many low-income countries (LICs).

Lichens are widely used as bioindicators. If air is very badly polluted, there may be no lichens present, just green algae. If the air is clean, lichens become abundant. A few lichen species can tolerate quite high levels of pollution and may be found on pavements, walls and tree bark in urban areas. The most sensitive lichens are shrubby and leafy, whereas the most pollution-tolerant lichens are crusty in appearance. Since industrialisation, many of the shrubby and leafy lichens such as *Ramalina Usnea* and *Lobaria* species have declined in their range. Some species of lichens have become more widely distributed as they are more tolerant of acidic conditions; examples include *Bryoria*, *Parmeliopsis*, *Pseudevernia* and *Rinodina*.

Key definition

Lichen – a symbiotic relationship formed by a fungus and an alga.

Figure 6.26 Lichens on an apple tree in a relatively unpolluted area



Source: Cislaghi C, and Nimis PL, 1997, 'Lichens, air pollution and lung cancer', Nature. 387(6632):463–4

Figure 6.27 Lichen diversity and lung cancer mortality in China. The lower figures in the lichen biodiversity index indicate less biodiversity (and more air pollution). The higher figures for lung cancer mortality indicate a higher the death rate (possibly due to poor air quality)

Most lichen studies involve the use of a transect from one area of high pollution to an area of lower pollution, for example, a town centre to the periphery of a town. Use a lichens key to note down the diversity and percentage of lichens at each sample point. If two comparative sites are being used, take a minimum of ten random samples/trees at each point. Sample the lichens at similar height (1 m) on all aspects of tree trunks/wall sets.

However, be aware that lichens do not indicate the source of the sulphur dioxide pollution – they merely show its effects.

Expert tip

Correlation does **not** mean causation. For example, there is a **correlation** between lichen biodiversity and lung cancer mortality in China, but lichen biodiversity (or the lack of it) does not **cause** lung cancer – something else affects lung cancer and lichen biodiversity.

Lichens and the weathering of rocks

The following results were taken from an investigation into the rate of weathering on gravestones in an urban environment.

Index number	Classification	Description
1	Unweathered	Corners of letters sharp
2	Slightly weathered	Rounding of corners of letters
3	Moderately weathered	Lettering legible
4	Badly weathered	Lettering difficult to read
5	Very badly weathered	Lettering illegible
6	Extremely weathered	Lettering disappeared

Table 6.6 Simplified Rahn's index

Figure 6.28 The lettering on this gravestone is difficult to read – Rahn's index of 4

The following assumptions can be made of the gravestone in Figure 6.28:

1. The date on the gravestone is the date that the gravestone was erected.
2. The proportion of lichen cover is a surrogate for the amount of weathering that has taken place.
3. The lettering was originally cut to the same depth.

Expert tip

Remember to have an environmental issue in your investigation, for example, air quality, acidification, pollution, etc.

ACTIVITIES

Gravestone	Rock type	Lichen cover (%)			Date on stone	Rahn's index
		Total	East	West		
1	Limestone	196	98	98	1848	5
2	Limestone	200	100	100	1865	5
3	Limestone	147	66	81	1896	5
4	Limestone	170	79	91	1891	5
5	Limestone	143	68	75	1909	4
6	Sandstone	140	61	79	1898	4
7	Sandstone	103	40	63	1937	3
8	Sandstone	119	55	64	1939	3
9	Sandstone	74	0	74	1949	2
10	Marble	74	35	39	1954	2
11	Marble	49	0	49	1965	2
12	Marble	27	11	19	1974	1

Table 6.7

10 a Choose an appropriate graph to show the relationship between the age of rock and the amount of lichen cover.
 b Describe the pattern you have found.
 c Suggest reasons to explain the pattern that you have found.
 d Suggest reasons why any anomalies might exist.
 e Describe the relationship between Rahn's index and the
  i age of rock
  ii amount of lichen cover
  iii rock type.

Sampling air pollution

Particulates in precipitation

Fold a piece of filter paper, insert it into a plastic funnel and place it into a rain gauge. Any particulates will be deposited on the paper as the rain enters the rain gauge. Leave for 24 hours then oven-dry the filter paper at about 100 °C overnight. Carefully remove the particulates and weigh them using a sensitive electronic balance. It is possible to work out the mass of particulates for a given volume of precipitation if you measure the volume of rainwater collected.

■ Airborne particulates

Place white card on to some hardboard and attach this to a piece of wood so it can be secured to the ground. Alternatively, attach to a standing object at 2–3 m above ground level, beyond passing reach, for example, telegraph poles, lampposts, and trees. Remove at weekly intervals and examine as above.

Stick on six 2-cm strips of masking tape, removing one strip each day. At the end of 5 days, remove the control strip and compare the density of particulate coverage between the strips. You can use a 10 cm × 10 cm quadrat or analyse under a microscope. The first strip should have the most particulate matter by the end of the sampling period, as it has been exposed the longest.

Ideally, samples of particulates should be taken as close as possible to the point sources of pollution and a control site.

It is also relatively easy and cheap to collect data for air quality using very basic materials. For example, variations in the amount of dust and solid matter in an area can be assessed by placing many clean, empty yoghurt pots around the area. The area should include a mix of locations (for example, road junctions, commercial areas, residential areas, parks and woodlands, rivers, power stations, and so on). If possible, attach the pots to buildings or structures (for example, lampposts) at 2–3 m high in as many different locations as possible. Setting the pots this high reduces the chance of interference from the public. Leave the pots for a period – this could be up to several weeks over the summer vacation. At the end of the time period, collect the pots and measure the amount of dust and particulate matter. Alternatively, with a digital camera, photograph the material in the pot and estimate the percentage of the base that is covered with dust.

As an alternative to using pots, coat cards with a sticky substance such as Vaseline. Hang the cards in a variety of locations (for example, around your school) and estimate the percentage covering of dust or amount of discolouring after a set time period (for example, 1–7 days).

It is possible to combine either of these methods with a survey on the variation in the amount of weathering of local rocks.

Ideas for investigations

The impact of traffic on air quality in a town

Traffic surveys are always a good option for local fieldwork since the data can be collected in close proximity to your school or home. Road vehicles are a major source of many pollutants in urban areas. They are responsible for over 50% of the emissions of nitrogen oxides and over 75% of carbon monoxide emissions in the UK.

Produce a base map of the selected survey area and identify sample locations. These could be arranged as transects from a CBD outward, for instance, or a comparison of two or more areas or a transect across a valley.

- Measure particulates.
- Carry out a traffic survey.
- Produce a questionnaire to determine people's attitudes to local air quality.

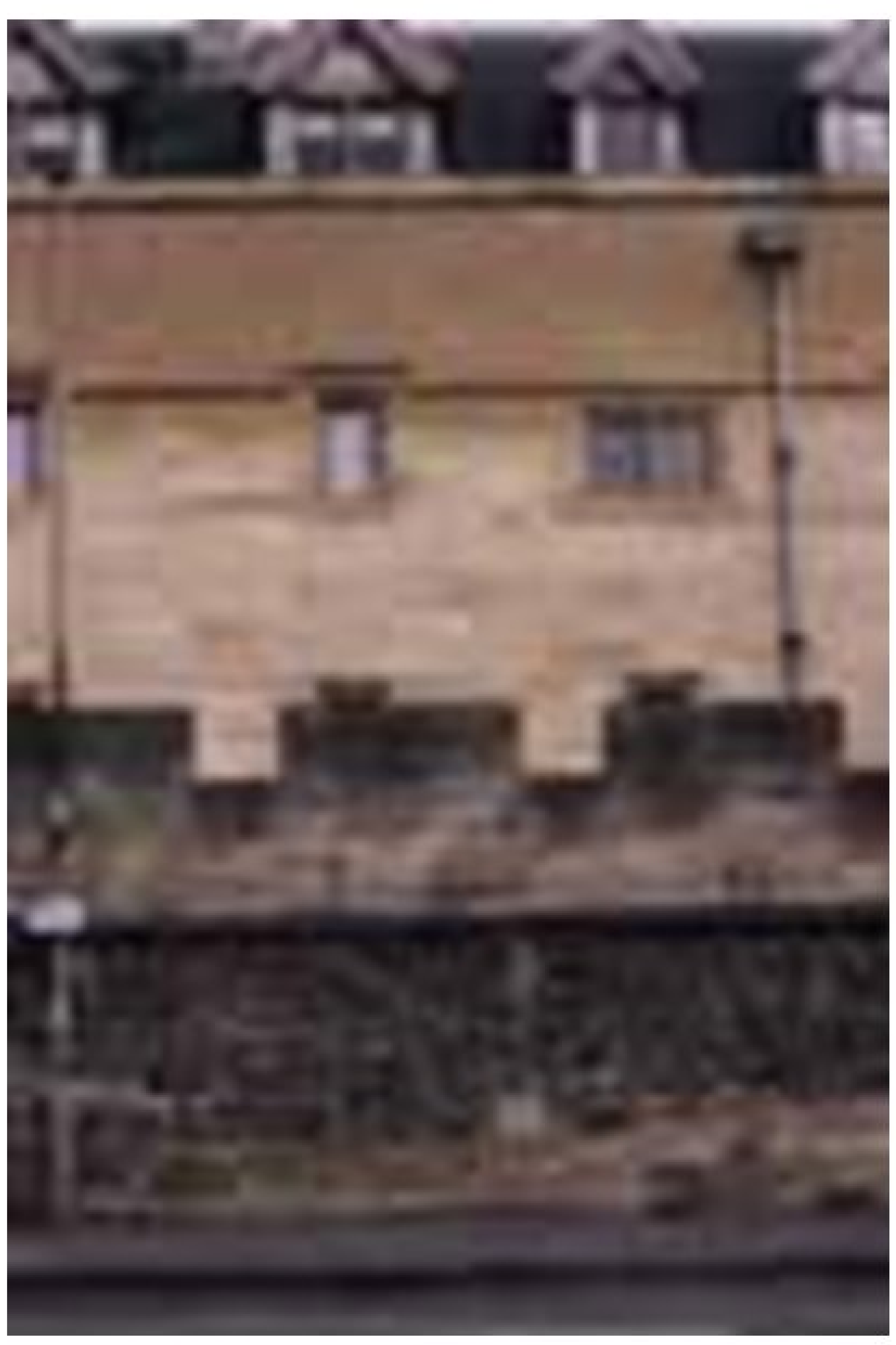


Figure 6.29 Wall polluted by traffic emissions, Worcester College, Oxford (UK), and a cleaned wall behind

Worked example

Analysing variations in air quality in Pabna City, Bangladesh, using the chi-squared technique

Location	Description	Suspended sediment ($5\ \mu m\ m^{-3}$)
Main bus terminal	Commercial area with heavy traffic	120
Gachpara	Industrial area with heavy traffic	56
Ononto Mor	Suburban area with medium traffic	37
Library Bazar	Residential area with low traffic	58
Traffic Mor	Commercial area with medium traffic	44

Source: Based on data in Hasan, R., et al., 2016, 'Status of air quality and survey of particulate matter pollution in Pabna City, Bangladesh', American Journal of Engineering Research. 5, 11, 18–22

Table 6.8 Study sites in Pabna City, Bangladesh

See pages 134–136 to see how to perform this test.

Null hypothesis: there is no variation in the level of suspended sediment around Pabna City.

Alternative hypothesis: there is a variation in the level of suspended sediment around Pabna City.

If there is no variation in the quality of air, all locations should have the same amount of suspended particulates, that is, the average.

Location	Observed suspended sediment (5 μm m) *(O)*	Expected value *(E)*	$O - E$	$(O - E)^2$	$\frac{(O-E)^2}{E}$
Main bus terminal	120	63	57	3249	51.57
Gachpara	56	63	–7	49	0.78
Ononto Mor	37	63	–26	676	10.73
Library Bazar	58	63	–5	25	0.40
Traffic Mor	44	63	–19	361	5.73
	$\bar{x} = 63$				$\Sigma = 69.21$

Table 6.9

For four degrees of freedom, the critical values are 9.49 at the 95% level and 13.28 at the 99% level of significance. Thus, we can reject the null hypothesis at the 99% level of significance and state that there is a significant variation in air quality in Pabna City.

Ideas for investigations

The effects of acid deposition on an area

Acid rain is defined as any type of precipitation which has a pH of less than 5.6. Acid rain in the context of pollution is rain that has been made more acidic due to human activities, namely the release of SO_2 and NOx. These may be transported hundreds of kilometres in the atmosphere, leading to transboundary pollution (wet deposition), or they may be transported tens of kilometres to form dry deposition.

It is absolutely vital that you focus on your title first:

1 to consider how serious a problem acid rain is in your chosen area
2 to look for likely sources within the local area which might contribute to it – thermal power stations or large factories are likely point sources as well as general traffic pollution.

Wet monitoring involves the collection of precipitation in a rain gauge. The container or gauge and funnel must be washed with deionized water. Test the pH of the water with a pH meter or pH test strips. Try to be accurate to at least 0.2 pH as there may only be subtle changes in the levels of pH. Monitor at different times and dates.

Dry monitoring: lichens make good indicators of air pollution, especially of SO as this affects both the growth rate and the species type. A gravestone survey may be useful.

Figure 6.30 Statues weathered by acid rain

You will need to support your primary data collection programme with research into the local sources of acid emissions, for example, power stations or industrial facilities. If a local source is identified, you may want to make this the focus of your investigation.

Preceding (antecedent) weather conditions may have significant impacts on the results. After a long dry spell, acidic substances can build up in the atmosphere, ready to be flushed out by the first rainfall. This might give an abnormally high level of acidity.

Secondary weather data on wind speed and direction may also help with the analysis of likely sources. The website **https://www.metoffice.gov.uk/datapoint/product/uk-hourly-site-specific-observations** includes data for many weather stations around the UK and includes wind speed and direction.

ENVIRONMENTAL ISSUES

- Air quality is a major problem in many urban areas.
- Air quality varies with air pressure – high-pressure conditions are much more likely to produce poor air quality than low-pressure conditions.
- Large urban areas modify their climate and this may cause problems for many residents.
- Forests modify their microclimate and this may be important in reducing wind speed, especially for farmers and in areas where frequent high wind speeds are a problem.

Ideas for investigations

- Examine the variations in microclimate along a transect from an area of open farmland into an area of woodland.
- Examine how weathering of gravestones is influenced by location (urban/rural), rock type, pollution, age of rock and/or aspect.
- Examine the variations in particulate matter in selected locations around a city.
- Investigate variations in microclimate around your school, college or home.

7 Climate change

Introduction

Climate change operates on many timescales, ranging from the geological past to the last thirty years. Climate change has operated over millions of years, hundreds of thousands of years, millennia, centuries and decades. As climate is defined as the 'average and extremes of weather over a period of not less than thirty years', it is difficult to examine climate change over a shorter time period. This is why many of the diagrams that show climate change will do so for at least one hundred years. This removes the impact of annual variations.

It is therefore impossible to collect primary data for climate change, and so secondary data must be used. A number of sources are listed at the end of this chapter. These sources provide statistics, graphs and maps for climate change data, rather than details on how climate change is inferred (ice core, oxygen isotope analysis, pollen analysis, pH levels of the oceans, glacier advances and retreats).

Figure 7.1 Global warming – even glaciers are getting warmer

Long-term climate change

Levels of carbon dioxide in the atmosphere have corresponded closely with temperature over the past 800 000 years. Although the temperature changes were caused mainly by variations in Earth's orbit, a positive-feedback system existed whereby increased global temperatures released CO_2 into the atmosphere, which in turn warmed the Earth. The highs and lows of carbon dioxide mark the main cold glacial periods (low carbon dioxide levels) and warm interglacial periods (high carbon dioxide levels). Throughout these cycles, atmospheric carbon dioxide was never higher than 300 ppm. In 2017, it reached 406 ppm.

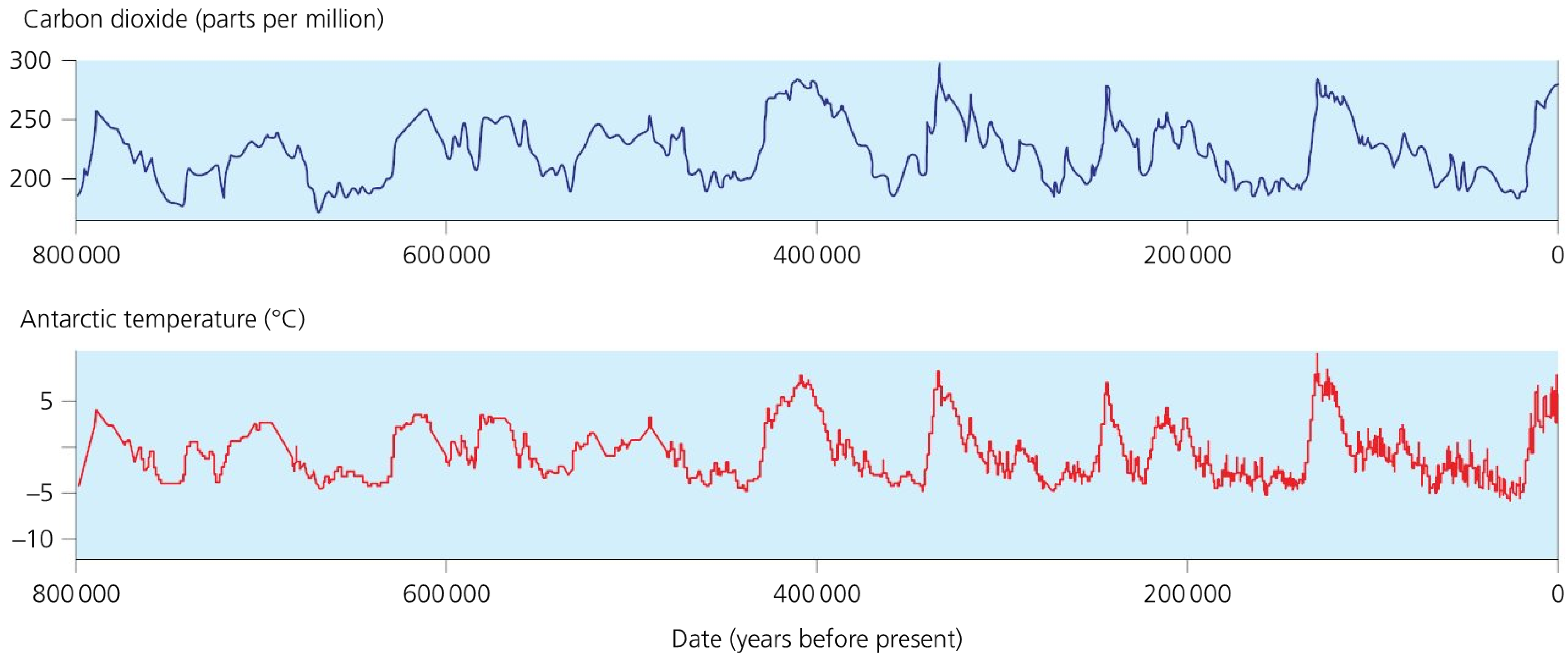


Figure 7.2 Climate change and CO_2 levels over the last 800 000 years

■ ACTIVITIES

1 **a** Describe the changes in average temperature in Antarctica and atmospheric CO_2 levels.

b **i** Suggest why higher atmospheric CO levels may lead to higher average temperatures.

ii Suggest how higher temperatures may lead to higher CO_2 levels.

iii Comment on the possible role of positive feedback in climate change.

Worked example

Moving means

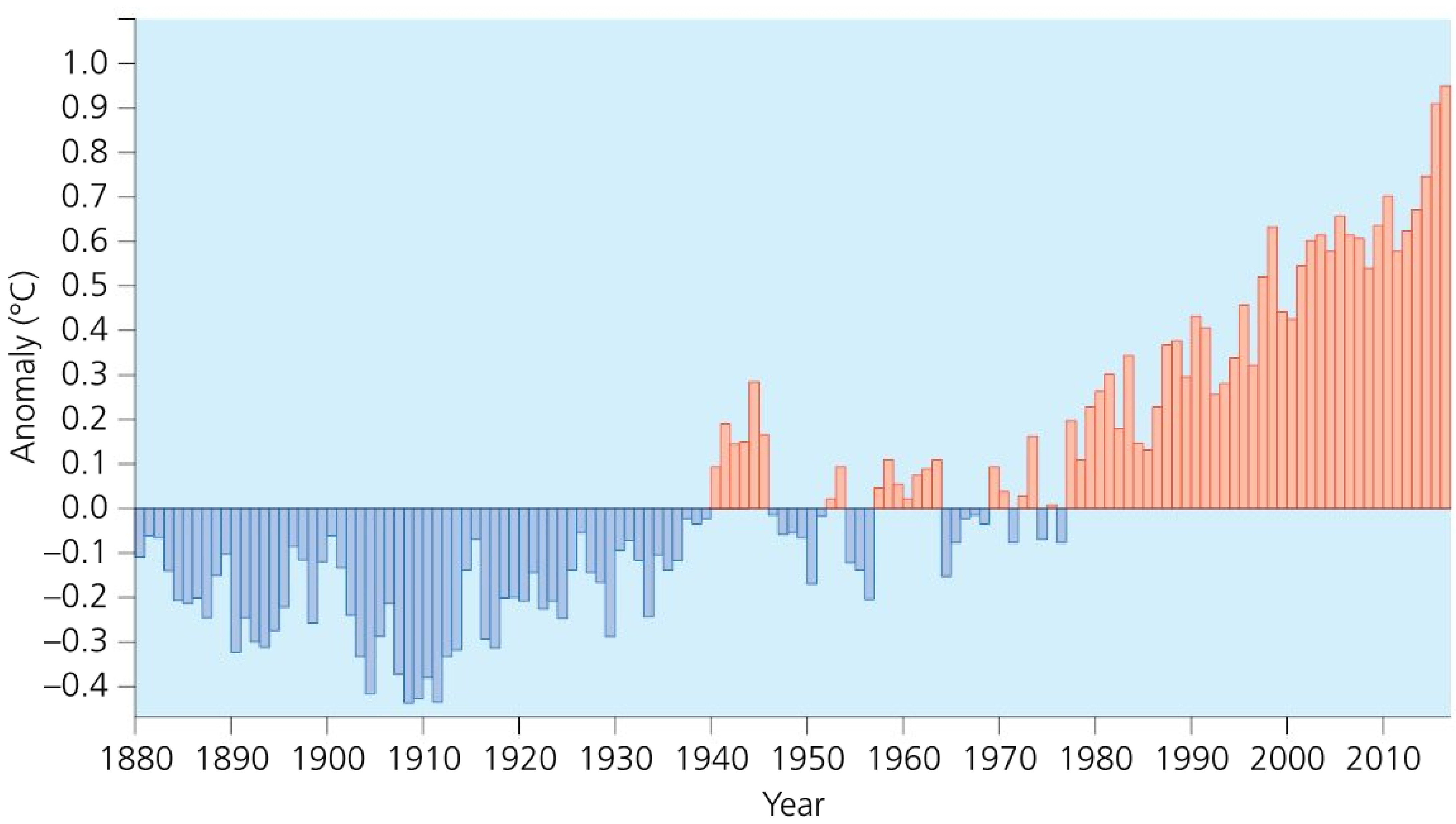


Figure 7.3 Global land and ocean temperature anomalies, 1880–2016 (relative to 1900–2000 average)

The graph of temperature anomalies in 1880–2016 (Figure 7.3) shows many variations from year to year. We can reduce these variations by taking a longer timescale, for example, the mean over three years or over five years. This reduces annual fluctuations but shows long-term trends more clearly. To work out a three-year mean, take the individual readings for three consecutive years, add them up and divide by three. For example, the three-year mean for 2000–02 is:

$$\frac{0.43 + 0.55 + 0.60}{3} = 0.53\ °C \text{ (rounded up)}$$

The next three years run from 2001–03, followed by 2002–04, and so on.

Table 7.1 shows the three-year moving mean from 2000–16. Notice that the first three-year moving mean is shown for 2000–02, the second for 2001–03, and so on. The first two five-year moving means have also been completed. Figure 7.4 shows the three-year moving mean for 2000–16.

ACTIVITIES

2 **a** Complete Table 7.1 by filling in the five-year moving means for 2003–07 to 2012–16.

b Draw a line graph for the five-year moving mean.

c Compare the graph for the five-year moving mean with that of the three-year moving mean (Figure 7.4).

d Outline how the use of moving means is a useful tool for studying climate change.

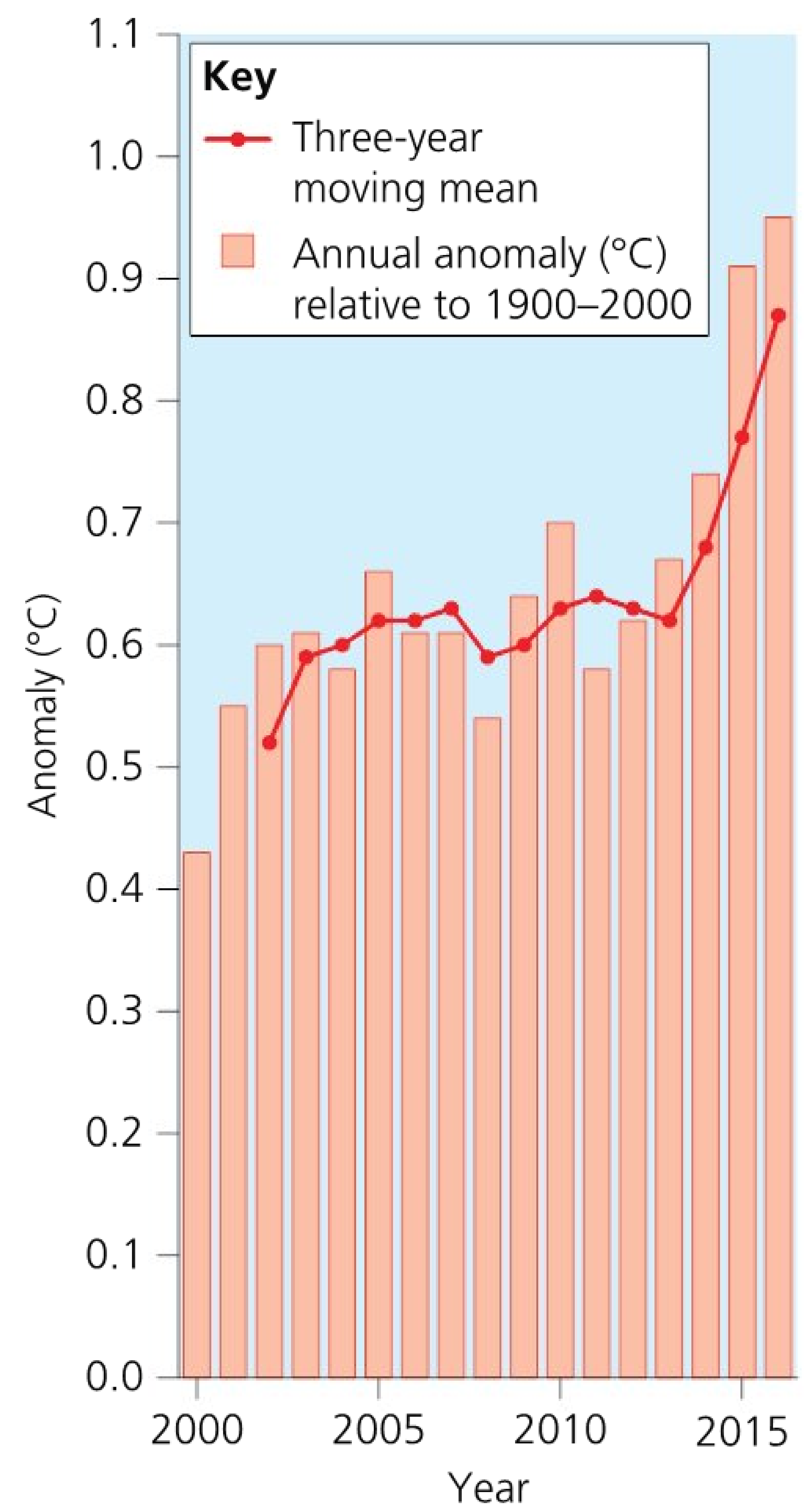


Figure 7.4 Annual temperature anomalies, 2000–16, and three-year moving mean

Year	Anomaly (relative to 1900–2000)	Three-year moving mean (years)	Three-year moving mean (°C)	Five-year moving mean (years)	Five-year moving mean (°C)
2000	0.43 °C	–	–	–	–
2001	0.55 °C	–	–	–	–
2002	0.60 °C	2000–02	0.52	–	–
2003	0.61 °C	2001–03	0.59	–	–
2004	0.58 °C	2002–04	0.60	2000–04	0.56
2005	0.66 °C	2003–05	0.62	2001–05	0.60
2006	0.61 °C	2004–06	0.62	2002–06	0.61
2007	0.61 °C	2005–07	0.63	2003–07	
2008	0.54 °C	2006–08	0.59	2004–08	
2009	0.64 °C	2007–09	0.60	2005–09	
2010	0.70 °C	2008–10	0.63	2006–10	
2011	0.58 °C	2009–11	0.64	2007–11	
2012	0.62 °C	2010–12	0.63	2008–12	
2013	0.67 °C	2011–13	0.62	2009–13	
2014	0.74 °C	2012–14	0.68	2010–14	
2015	0.91 °C	2013–15	0.77	2011–15	
2016	0.95 °C	2014–16	0.87	2012–16	

Table 7.1 Temperature anomalies 2000–2016, three-year moving mean and five-year moving mean

Carbon dioxide

Keeling curve

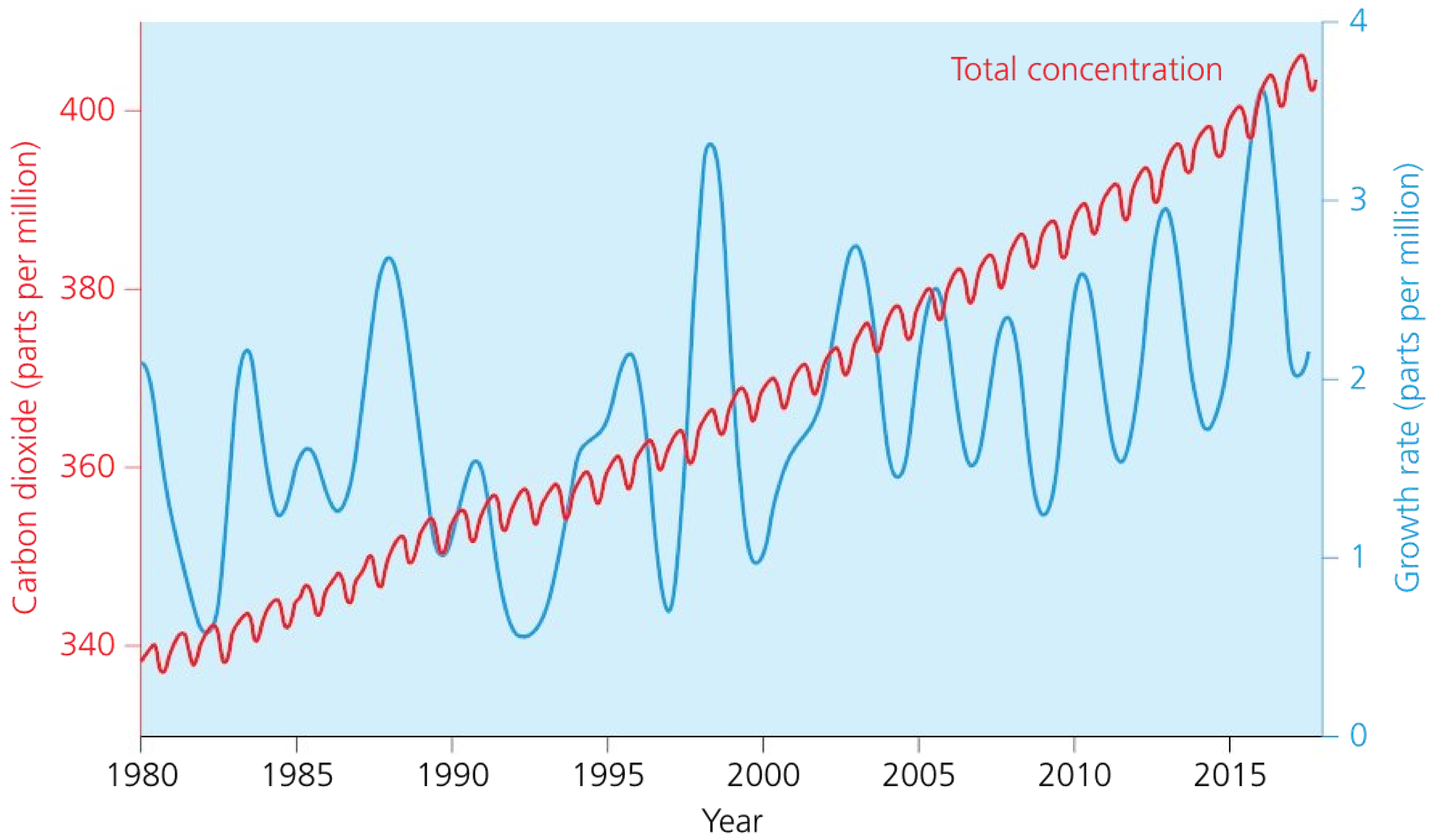


Figure 7.5 Keeling curve showing annual and seasonal trends in atmospheric CO_2, 1980–2017

The Keeling curve is a graph that shows seasonal and annual changes in atmospheric CO_2. The overall annual trend is upwards, whereas there are seasonal changes in which photosynthesis and respiration take up CO_2 in spring and release it in autumn and winter.

ACTIVITIES

Year (readings taken from 15th June)	Average atmospheric CO_2 concentration (ppm)	Year (readings taken from 15th June)	Average atmospheric CO_2 concentration (ppm)	Year (readings taken from 15th June)	Average atmospheric CO_2 concentration (ppm)	Year (readings taken from 15th June)	Average atmospheric CO_2 concentration (ppm)
1958	315	1973	330	1988	351	2003	376
1959	316	1974	330	1989	352	2004	377
1960	317	1975	331	1990	354	2005	380
1961	318	1976	332	1991	355	2006	382
1962	318	1977	333	1992	356	2007	383
1963	319	1978	335	1993	357	2008	385
1964	320	1979	337	1994	359	2009	387
1965	320	1980	339	1995	361	2010	390
1966	321	1981	340	1996	363	2011	391
1967	322	1982	341	1997	364	2012	394
1968	323	1983	343	1998	367	2013	396
1969	325	1984	344	1999	368	2014	399
1970	326	1985	345	2000	369	2015	401
1971	326	1986	347	2001	371	2016	404
1972	327	1987	349	2002	373	2017	406

Table 7.2 Annual atmospheric CO_2 concentrations 1958–2017

3 **a** Using Table 7.2 and a copy of Figure 7.6 below, plot the figures for annual atmospheric CO_2 concentration.

b Deduce the annual growth rate in atmospheric CO_2 and plot this using the scale on the right-hand side of the graph.

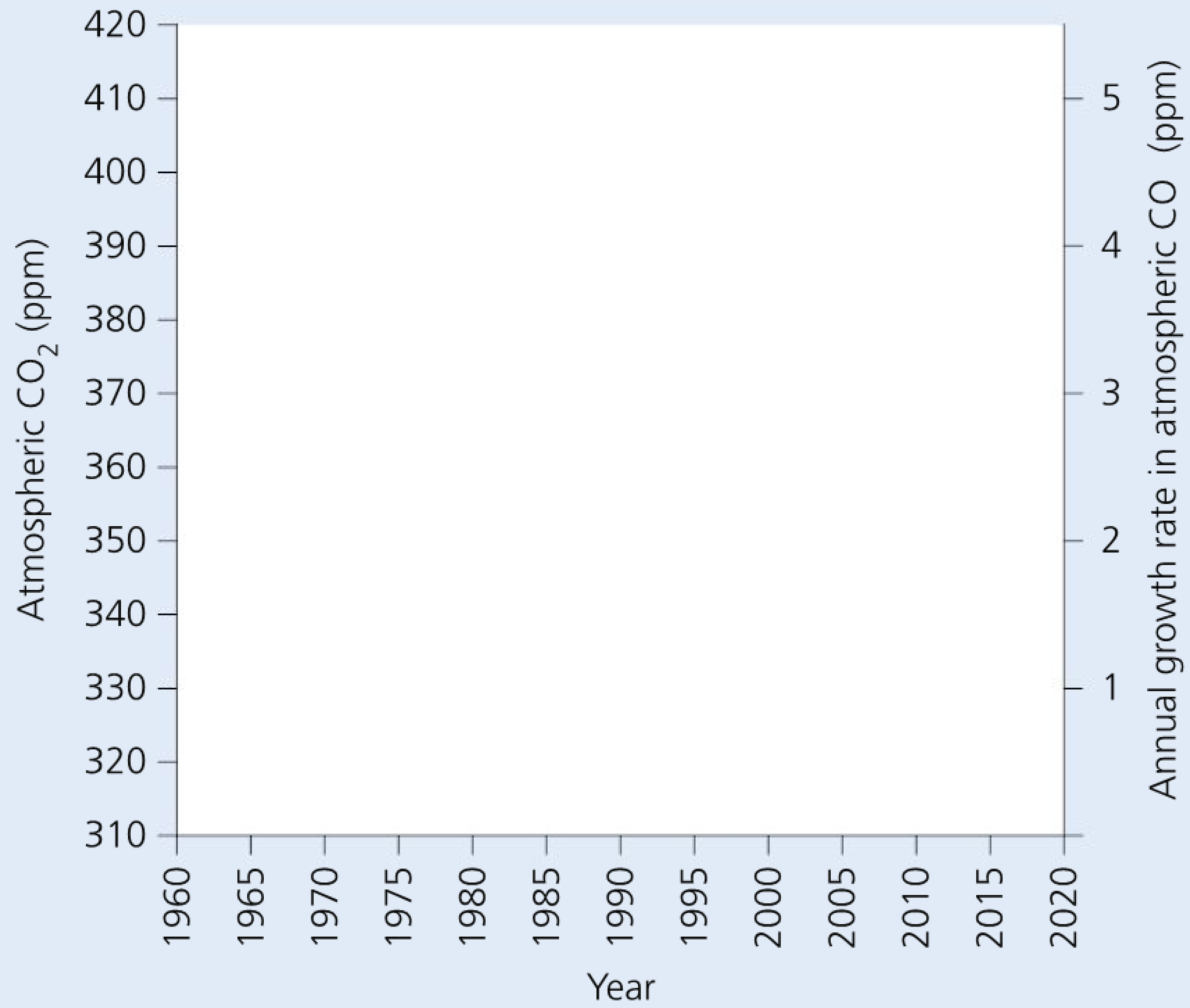


Figure 7.6

2016	Monthly CO_2 concentration (ppm)	2017	Monthly CO_2 concentration (ppm)	2018	Monthly CO_2 concentration (ppm)
J	402.85	J	405.68	J	407.58
F	403.86	F	406.57	F	408.42
M	404.98	M	407.54	M	409.34
A	406.51	A	408.97	A	410.72
M	407.3	M	409.71	M	410.7
J	406.68	J	409.03	J	409.7
J	405.15	J	407.44	J	
A	403.02	A	405.25	A	
S	401.31	S	403.45	S	
O	401.44	O	403.5	O	
N	403.01	N	405.01	N	
D	404.53	D	406.49	D	

Source: http://scrippsco2.ucsd.edu/data/atmospheric_co2/primary_mlo_co2_record (and from here you can update these statistics)

Table 7.3 Monthly CO_2 concentrations (ppm), January 2016–June 2018

4 **a** Copy and adapt Figure 7.6 and plot the data for seasonal variations in CO_2 emissions.

b Identify two trends in the data that you have plotted.

Age and carbon footprint

ACTIVITIES

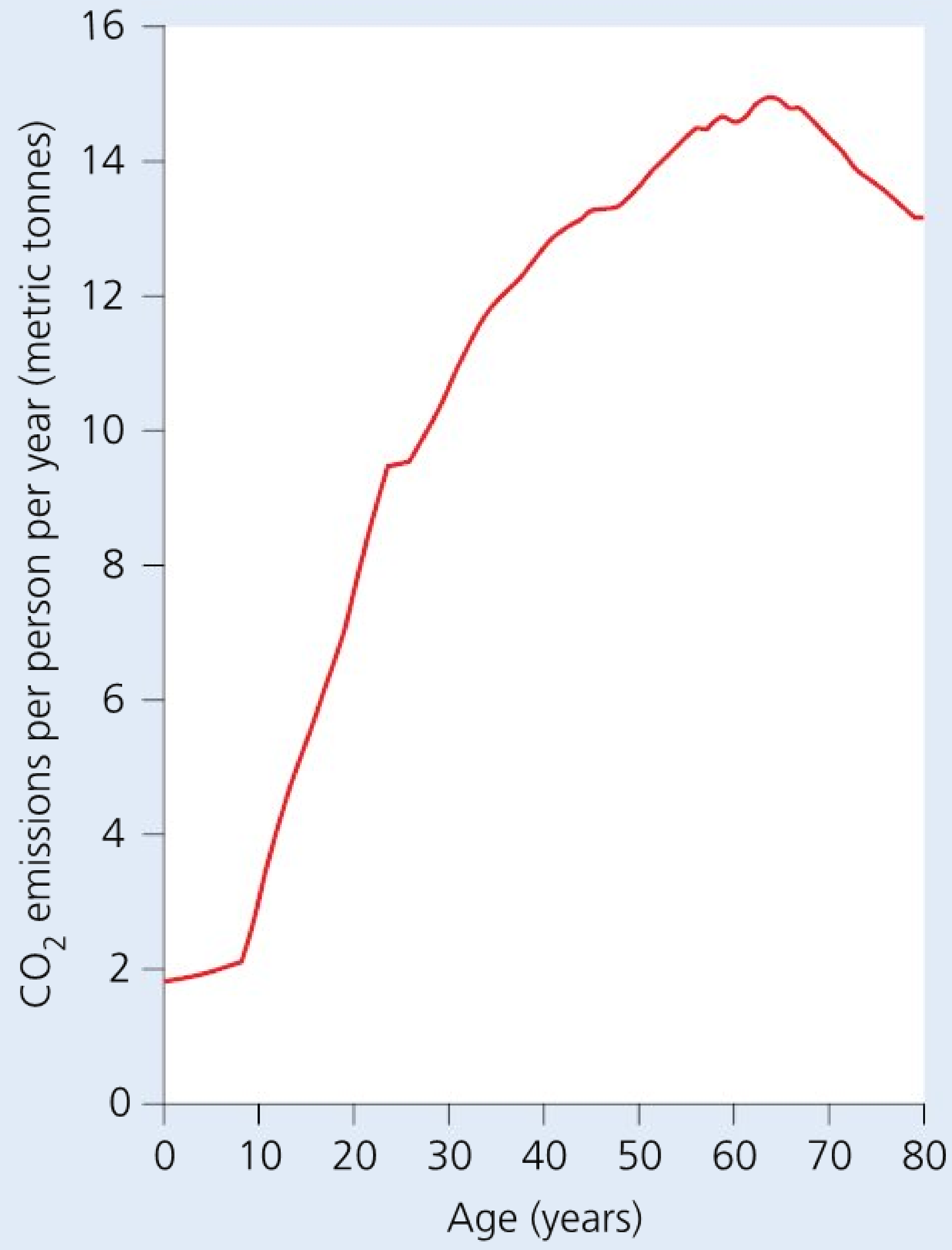


Figure 7.7 CO_2 emissions by age group

5 **a** Describe variation in the carbon footprint associated with

under ten-year olds

ii 60-year olds

iii 80-year olds.

b **i** Identify the ages when the increase in CO_2 emissions per person per year is greatest.

ii Suggest reasons why this population group has the greatest increase in CO_2 emissions.

iii Briefly explain why the population age group with the highest CO_2 emissions is those aged around 60 years.

iv Justify **two reasons** why this is likely to be a high-income country.

v Suggest reasons why the CO emissions for people over the age of 60 years should decline.

Stratospheric ozone

The Dobson Unit

Ozone is a trace gas and is measured in **Dobson Units (DU)**. If all the ozone in a column of air stretching from the surface of the Earth to space were brought to 0 °C and a pressure of 1013 mb (one atmosphere, or 'atm'), the column would be about 0.3 cm thick. Thus, the total ozone would be 0.3 atm-cm. To make the units easier to work with, the Dobson Unit is defined to be 0.001 atm-cm. Thus, 0.3 atm-cm of ozone would be $\frac{0.3}{0.001}$ Dobson Units, that is, 300 DU.

Year	Ozone hole area (million km^2) 07 September–13 October	Dobson Units 21 September–16 October
1979	0.1	225.0
1980	1.4	203.0
1981	0.6	209.5
1982	4.8	185.0
1983	7.9	172.9
1984	10.1	163.6

Key definitions

Ozone hole – the thinning of the concentration of ozone in the stratosphere.

Dobson Unit (DU) – the unit of measure for total ozone.

Year	Ozone hole area (million km²) 07 September–13 October	Dobson Units 21 September–16 October
1985	14.2	146.5
1986	11.3	157.8
1987	19.3	123.0
1988	10.0	171.0
1989	18.7	127.0
1990	19.2	124.2
1991	18.8	119.0
1992	22.3	114.3
1993	24.2	112.6
1994	23.6	92.3
1996	22.8	108.8
1997	22.1	108.8
1998	25.9	98.8
1999	23.3	102.9
2000	24.8	98.7
2001	25.0	100.9
2002	12.0	157.4
2003	25.8	108.7
2004	19.5	123.5
2005	24.4	113.8
2006	26.6	98.4
2007	22.0	116.2
2008	25.2	114.0
2009	22.0	107.9
2010	19.4	128.5
2011	24.7	106.5
2012	17.8	139.3
2013	21.0	132.7
2014	20.9	128.6
2015	25.6	117.2
2016	20.7	123.2
2017	17.4	141.8

Source: https://ozonewatch.gsfc.nasa.gov/statistics/annual_data.html

Table 7.4 Ozone concentration (Dobson Units) and size of the ozone hole over Antarctica, 1979–2017

Key definition

Statistical significance – a calculated value that is used to establish the probability that an observed trend or difference represents a true difference that is not due to chance alone.

■ ACTIVITIES

6 **a** Plot the graph of the ozone hole area using the data provided in Table 7.4.

b Describe the changes in the ozone hole over Antarctica between January 1979 and September 2006.

c Using the website https://ozonewatch.gsfc.nasa.gov/, download an image of the current ozone hole over Antarctica. Describe the current situation of the Antarctic ozone hole.

d Investigate the relationship between the size of the ozone hole and the concentration of ozone in the stratosphere.

Identify the independent and dependent variables.

ii State the null hypothesis.

iii State the level of **statistical significance** at which the null hypothesis will be tested.

iv Use a scatter graph to show the relationship between the value of Dobson Units and the area of the ozone hole over Antarctica.

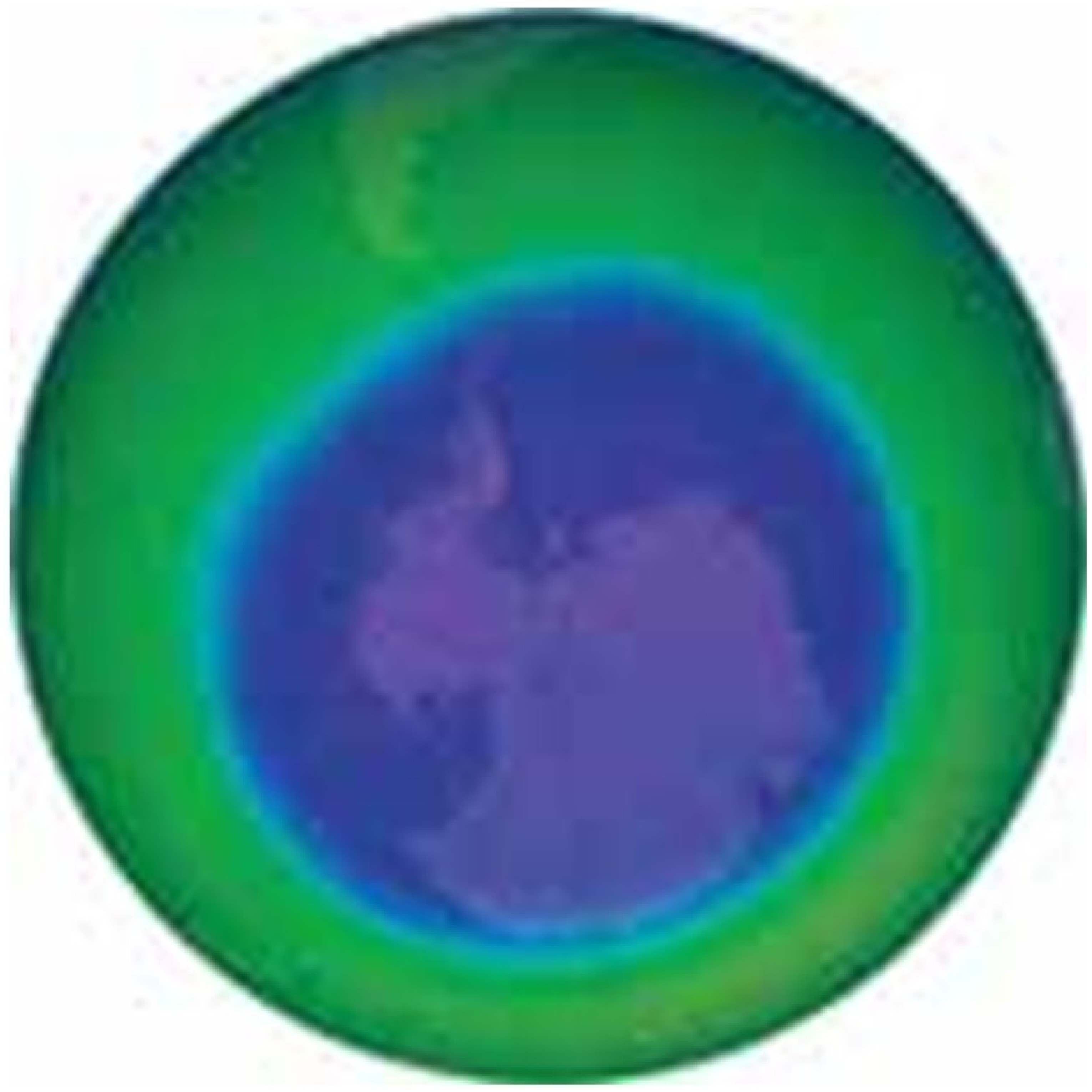
v Identify the statistical test to be used.

vi Compute the statistical test.

vii Compare with the critical values and make a conclusion about the level of statistical significance.

Source: https://ozonewatch.gsfc.nasa.gov/monthly/monthly_1979-01_SH.html

Figure 7.8a Ozone hole over Antarctica, January 1979



Source: https://ozonewatch.gsfc.nasa.gov/monthly/monthly_2006-09_SH.html

Figure 7.8b Ozone hole over Antarctica, September 2006

Changes in the length of the Gorner Glacier, Switzerland

Figure 7.9 The Gorner Glacier, Switzerland

Years*	Length change (m)	Cumulative length change (m)
1885–90	+4	+4
1890–95	–52	–48
1895–00	–29	–77
1900–05	–31	
1905–10	–34	
1910–15	–27	
1915–20	–55	
1920–25	–58	
1925–30	–40	
1930–35	–60	
1935–40	–61	
1940–45	–96	
1945–50	–187	
1950–55	–287	
1955–60	–139.7	
1960–65	–129.5	
1965–70	–135.6	
1970–75	–124.9	
1975–80	–212.0	
1980–85	–61.7	
1985–90	–93.1	
1990–95	–111.5	
1995–00	–124.8	
2000–05	–44.2	
2005–10	–328.4	
2010–15	–182	
2015–17	–92	

*Each five-year group contains five years, for example 1885–90 contains 1885–6, 1886–7, 1887–8, 1888–9 and 1889–90. The second group of five years begins with 1890–91

Up until 1955–56, data are provided in whole numbers.

Table 7.5 Length change in the Gorner Glacier, Switzerland from 1885–2017

■ ACTIVITIES

7 Using the data in Table 7.5 above:

- **a** Draw a series of bar charts to show the 5-year changes in the Gorner Glacier since 1885.
- **b** Complete the column for the cumulative change in the length of the Gorner Glacier.
- **c** Draw a line graph to show the cumulative change in the length of the Gorner Glacier since 1885.
- **d** Comment on how changes in the length of the Gorner Glacier suggest changes in global climate.

Ideas for investigations

There are many useful sources of secondary data. These include:

- Monthly climatic data for the world:
  https://www.weather-atlas.com/en/climate
- Fossil fuel emissions:
  http://cdiac.ess-dive.lbl.gov/pns/education_links.html
- State of the world's climate, 2017:
  https://www.ametsoc.net/sotc2017/StateoftheClimate2017_lowres.pdf
- Link to data for the ozone hole:
  https://ozonewatch.gsfc.nasa.gov/
- To view statistics for the retreat of glaciers in Switzerland, visit:
  http://swiss-glaciers.glaciology.ethz.ch/
- To view annual changes in the Gorner Glacier visit:
  http://swiss-glaciers.glaciology.ethz.ch/download/gorner_en.pdf

ENVIRONMENTAL ISSUES

There are many issues related to global climate change, including changes in the cryosphere (ice), changes to stratospheric ozone, rising temperatures changes in climate conditions, changes to biomes, rising sea levels, and changes in the incidence of disease.

8 Population and resources

Human population dynamics

The **demographic transition model** (DTM) is a model that shows how a country changes from a pre-industrial society with high **birth rates** and **death rates** to a society with low birth rates and death rates. However, not every country follows the same path, and there are differences between high-income countries and low-income countries, notably in the speed with which demographic change occurs.

Key definitions

Demographic transition model – the change from high birth and death rates to low birth and death rates (expressed in rates per thousand).

Birth rate – the number of live births in a population per 1000 people per year.

Death rate – the number of deaths in a population per 1000 people per year.

Natural change – birth rate minus death rate (expressed as a percentage).

Natural increase – when birth rates are higher than death rates (expressed as a percentage).

Natural decrease – when death rates are higher than birth rates (expressed as a percentage).

ACTIVITIES

1 Table 8.1 shows demographic data for Mexico, 1900–2050.

Year	Birth rate (‰)	Death rate (‰)	Natural increase (%)	Total population (million)
1900	34.0	32.7		13.6
1910	33.0	32.0		15.2
1914	30.0	38.0		14.7
1920	31.0	33.0		14.3
1930	49.5	26.7		16.7
1940	44.3	22.8		19.7
1950	45.6	16.1		25.8
1960	46.1	11.5		34.9
1970	44.2	10.1		48.2
1980	36.3	6.5		66.8
1990	33.8	5.2		81.2
2000	21.1	4.5		97.5
2005	19.3	4.8		103.9
2010	17.8	5.0		108.4
2020	15.7	5.6		115.8
2030	13.6	6.6		120.9
2040	11.9	8.1		122.9
2050	11.1	9.8		121.9

Source: Rhoda, R. and Burton, T., 2010, *Geo-Mexico: the geography and dynamics of modern Mexico*, Sombrero Books

Table 8.1 Demographic data for Mexico, 1900–2050

- **a** Using an appropriate grid, plot the data for Mexico's birth rates and death rates.
- **b** Describe the stages in Mexico's demographic transition.
- **c** Plot the data for Mexico's total population.
- **d** Describe Mexico's population growth over time.
- **e** Work out the changes in natural increase (birth rate minus death rate converted into a percentage) between 1900 and 2050.
- **f** Suggest reasons for the variations in natural change in Mexico between 1900 and 2050.

Investigating ecological footprints

The **ecological footprint** is a model that shows whether a population is living within its **carrying capacity**. Table 8.2 presents the ecological footprint, and its composition, for a range of countries.

ACTIVITIES

Country	Ecological footprint (EF) (gha)	Food (% of EF)	Housing (% of EF)	Mobility (% of EF)	Goods (% of EF)	Services (% of EF)
USA	8.4	18	25	28	14	15
Germany	5.0	24	27	26	16	7
China	3.7	35	31	15	11	8
Argentina	3.7	51	17	17	10	5
Tanzania	1.5	74	20	2	3	1

Source: http://awsassets.panda.org/downloads/lpr_living_planet_report_2016.pdf

Table 8.2 Ecological footprints for a range of countries

2 **a** Using proportional pie charts, display the data in Table 8.2.

- **b** Outline the main characteristics of the USA's and Tanzania's ecological footprint.
- **c** Compare and contrast the ecological footprints of China and Argentina.
- **d** Suggest reasons for the difference between the ecological footprints of high-income countries and low-income countries.

Key definitions

Ecological footprint – the hypothetical area of land and water required to support a defined population at a given standard of living, measured in global hectares (gha). The measure takes account of the area required to provide all the resources needed by the population and the disposal of waste materials.

Carrying capacity – the maximum size of a population that can be sustainably supported within an area.

Expert tip

Ecological footprints vary in terms of size (quantity) and composition (quality). Ecological footprints can be calculated for a whole country (total ecological footprint) or per person (EFP/capita).

Expert tip

The Human Development Report can be found at http://hdr.undp.org/en/

Worked example

Investigation: development and ecological footprints

In this IA, published data from the Human Development Report, the CIA World Factbook and the Living Planet are used to investigate the relationship between levels of human development, gross national income and ecological footprints.

Planning

- Clearly state the aim of the research question to be investigated, for example, *There is a relationship between level of development and ecological footprints.*
- Clearly state the null hypothesis, that is, *There is no relationship between levels of development, as measured by* ***Human Development Index (HDI)*** *and ecological footprints.*
- Define the key terms, in this case 'ecological footprint' and 'Human Development Index' and '**GNI**/person'.
- Briefly explain the theoretical relationship between the two variables.
- Identify the independent, dependent and control variables. In this example, GNI is the independent variable and ecological footprint is the dependent variable. This is because ecological footprint is influenced by the level of wealth in a country – rich countries generally have higher ecological footprints than poorer countries.
- Control factors include war and natural disasters – these could affect the results and so countries which are at war (for example, Yemen or Syria) or have suffered extreme natural disasters (for example, Indonesia) in recent years have been removed from the data collection.

Key definitions

Human development index (HDI) – the level of development of a population, taking into account life expectancy, literacy levels and wealth (purchasing power parity (PPP)).

GNI – gross national income; the sum of a nation's gross domestic product and the net income it receives from overseas.

Method

Collect data for eight countries in each of the four categories – very high HDI, high HDI, medium HDI and low HDI – using a random numbers table to select the first eight countries in each category that will appear in the table. The use of a random numbers table avoids bias and gives every country an equal chance of being used. For each country, record its HDI (Statistical Table 1 in the Report) and its ecological footprint (see **http://data.footprintnetwork.org/#/**).

32 countries are used here because 30 represents a 'large' sample in statistical terms and so should avoid bias.

Data collection

Include all relevant tables (including units) – this must be able to stand alone.

Very high HDI	GNI/head	Ecological footprint (gha)
Switzerland	65,190	4.85
Denmark	51,560	7.13
Japan	45,470	4.74
Spain	38,090	3.81
Malta	36,740	4.89
Slovakia	31,360	4.20
UAE	74,410	9.75
Romania	25,150	2.80
Mean	**45,996**	**5.27**
High HDI	**GNI/head**	**Ecological footprint (gha)**
Malaysia	28,650	4.42
Panama	21,890	2.32
Mauritius	21,600	3.50
Georgia	10,700	1.90
Venezuela	17,440	3.27
Mexico	17,740	2.55
Peru	12,890	2.29
Mongolia	11,170	9.50
Mean	**17,760**	**3.72**
Medium HDI	**GNI/head**	**Ecological footprint (gha)**
Moldova	6,060	1.92
Botswana	16,990	2.54
Turkmenistan	17,320	5.56
El Salvador	7,540	2.00
Morocco	8,063	1.75
Micronesia	4,210	5.68
Tajikistan	3,670	0.96
Zambia	3,920	0.95
Mean	**8,472**	**2.67**
Low HDI	**GNI/head**	**Ecological footprint (gha)**
Swaziland	8,520	2.40
Zimbabwe	1,850	1.09
Mauritania	3,900	2.30
Lesotho	3,510	1.46
Djibouti	3,600	2.94
Sierra Leone	1,480	1.23
Burkina Faso	1,810	2.98
Niger	990	1.76
Mean	**3,260**	**2.02**

Table 8.3 GNI and ecological footprints, sorted by HDI status

Processing of data

Calculate the mean for the HDI and ecological footprints for each of the four groups, by adding up the eight individual readings and then dividing by eight.

Use the Spearman's rank equation to see if the correlation is positive or negative and to see how significant it is. You must show all the workings and state the level of statistical significance at the end of your working.

Method

$$r_s = 1 - \frac{6 \sum d^2}{n^3 - n}$$

where

n = the number of observations

d = the difference in ranks

$\sum$ means 'the sum of'.

Significance levels for Spearman's rank

	95%
4	1.00

Table 8.4

The following shows a worked example, with units, for four categories.

Category (HDI)	GNI/ head ($)	Ecological footprint (EFP) (gha)	Rank GNI/ head	Rank/ EFP	Difference in ranks	Difference^2
Very high	45,996	5.27	1	1	0	0
High	17,760	3.72	2	2	0	0
Medium	8,472	2.67	3	3	0	0
Low	3,206	2.02	4	4	0	0
						$\Sigma = 0$

Table 8.5

$$R_s = 1 - \frac{6 \sum d^2}{n^3 - n}$$

$$R_s = 1 - \frac{(6 \times 0)}{4^3 - 4}$$

$$= 1 - \frac{0}{60}$$

$$= 1 - 0$$

$$= 1$$

Results

In the worked example of four categories, the results show a positive correlation, that is, as one variable increases the other decreases. The strength of the correlation, 1.0, tells us that it is 95% statistically significant.

Presentation of data

Graphs must show **processed** data, not raw data.

A box-and-whisker plot is used to show differences in the mean and range (that is, the difference between the maximum value and the minimum value) of the ecological footprints rates for different HDI categories.

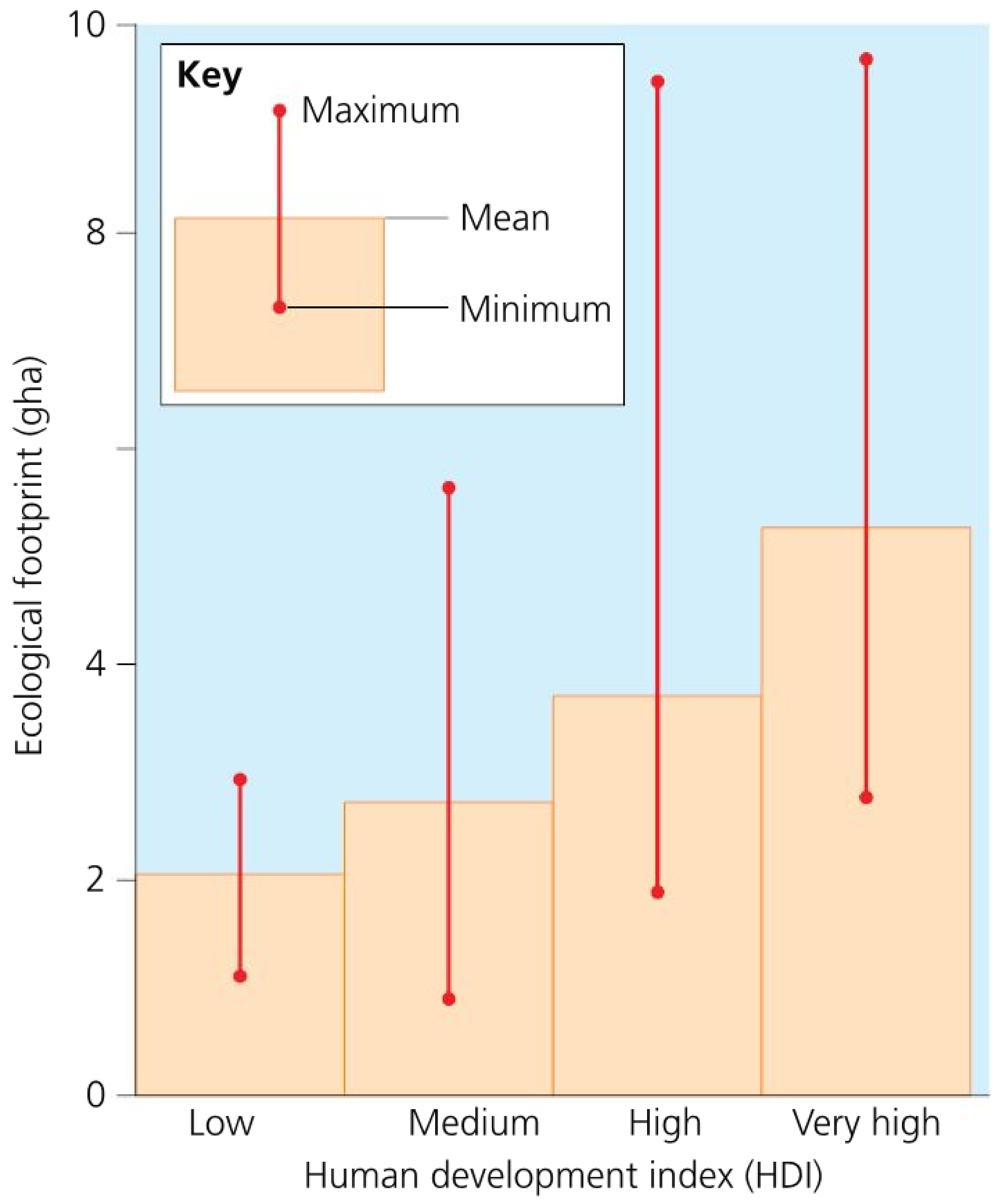


Figure 8.1 Box-and-whisker plot to show variations in the mean and range of ecological footprints for different HDI categories

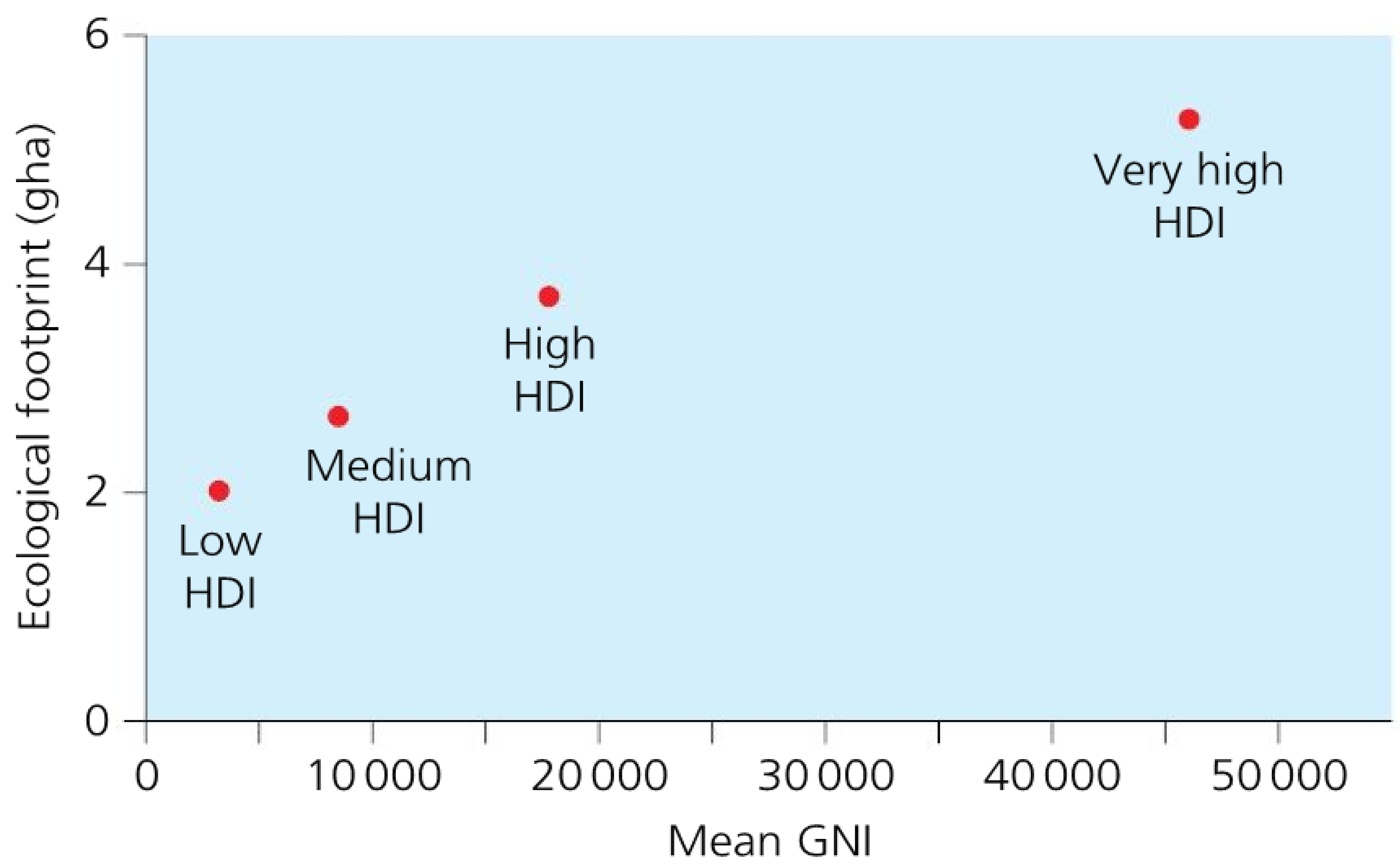


Figure 8.2 Scatter graph to show the relationship between ecological footprints and average GNI for different HDI categories

The most useful way of showing the data here is to use a scatter graph. The axes should be clearly labelled and units identified. Include a line of best fit – this does not have to be a straight line but could be a curved line.

Discussion

Fully describe the graph. Try to refer to specific data, in this case the ecological footprint and HDI of different categories. A useful method is to identify the maximum, minimum, the trend and exceptions to the pattern.

Explain the results, referring to relevant parts of the syllabus (in this case, carrying capacity and ecological footprints).

Evaluation

Outline limitations and weaknesses of the investigation. Is the data reliable? How could the data collection be improved? Could you use more countries? How might other indicators improve the quality of your investigation?

What are the limitations of the statistical test that you used? Why was the statistical test that you used an appropriate one?

Conclusions

Summarize the main findings of the study. Quote data from your study, for example, include the results of the statistical test.

Did the results confirm or reject the hypothesis? What was the level of statistical significance of your investigation?

Development and water and carbon footprints

ACTIVITIES

3 The data below show information on **purchasing power parity (PPP)** and water footprints.

Country	Purchasing power parity (PPP) ($)	Water footprint (litres/day)
Ireland	75 000	3 600
Norway	71 800	3 900
UAE	67 700	8 600
USA	59 500	7 800
Saudi Arabia	54 800	5 100
Australia	50 300	6 300
United Kingdom	44 100	3 400
South Korea	39 400	4 500
New Zealand	38 300	6 700
Malaysia	28 900	5 800
Russia	27 800	5 100
Chile	24 500	3 200
Uruguay	22 400	5 800
Mexico	19 900	5 400
Botswana	17 800	5 600
China	16 700	2 900
Brazil	15 600	5 600
Algeria	15 200	4 400
South Africa	13 500	3 400
Egypt	12 700	3 700
Venezuela	12 100	4 700
Namibia	11 300	4 600
India	7 200	3 000
Vietnam	6 900	2 900
Myanmar	6 200	3 300
Nigeria	5 900	3 400
Sudan	4 600	4 800
Bangladesh	4 200	2 100
Kenya	3 500	3 000
Tanzania	3 200	2 800
Senegal	2 700	3 200
Chad	2 300	4 000
Mali	2 200	5 600
North Korea	1 700	2 400
Yemen	1 300	2 500
DR Congo	800	1 500

Source: CIA World Factbook for PPP and water footprints at http://waterfootprint.org/en/resources/interactive-tools/national-water-footprint-explorer/

Table 8.6 Purchasing power parity and water footprints

Figure 8.3 shows the relationship between PPP and water footprints.

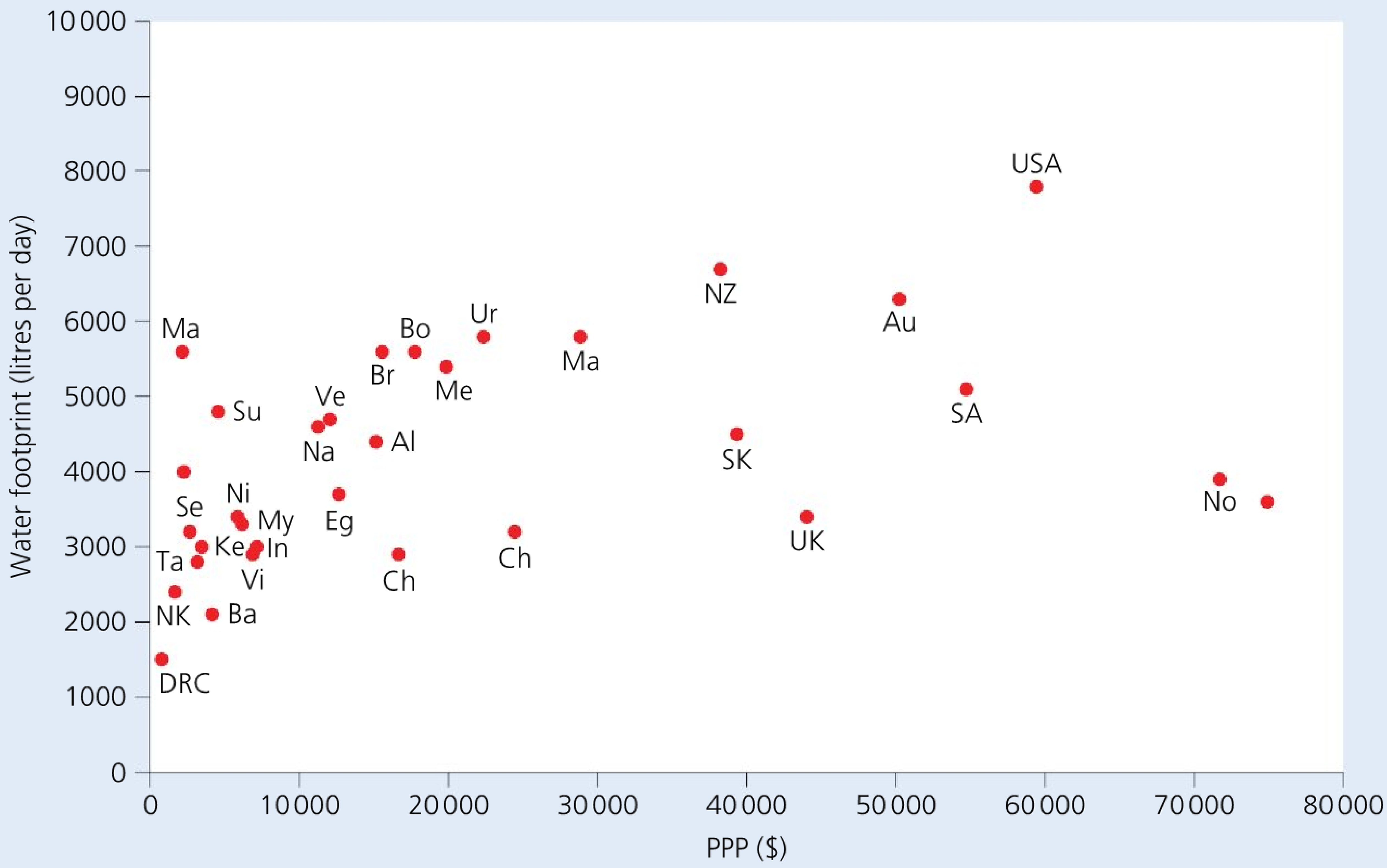


Figure 8.3 Scatter graph showing the relationship between PPP and water footprints

a On a copy of Figure 8.3, add the data for UAE, Russia, South Africa and Yemen (from Table 8.6).

b Describe the relationship between PPP and water footprint.

c Calculate Spearman's rank correlation, given that $\sum d^2$ is 2973.5. Comment on the form and the strength of the correlation.

Examiner guidance

Make sure that you use data from the graph. Refer to named examples and state their purchasing power parity (PPP) and water footprint. Useful examples to use are the maximum value, minimum value and any exceptions.

Key definition

Purchasing power parity (PPP) – local levels of income related to local prices.

PPP and carbon footprints

ACTIVITIES

4 The data below show information on purchasing power parity (PPP) and CO emissions.

Country	Purchasing power parity (PPP) ($)	CO_2 emissions (metric tonnes per capita)
Ireland	75 000	7.3
Norway	71 800	9.3
UAE	67 700	23.3
USA	59 500	16.5
Saudi Arabia	54 800	19.5
Australia	50 300	15.4
United Kingdom	44 100	6.5
South Korea	39 400	11.6
New Zealand	38 300	5
Malaysia	28 900	8
Russia	27 800	11.9
Chile	24 500	4.7
Uruguay	22 400	2
Mexico	19 900	3.9
Botswana	17 800	3.2
China	16 700	7.5
Brazil	15 600	2.6
Algeria	15 200	3.7
South Africa	13 500	9
Egypt	12 700	2.2
Venezuela	12 100	6
Namibia	11 300	1.6
India	7 200	1.7
Vietnam	6 900	1.8
Myanmar	6 200	0.4
Nigeria	5 900	0.5
Sudan	4 600	0.3
Bangladesh	4 200	0.5
Kenya	3 500	0.3
Tanzania	3 200	0.2
Senegal	2 700	0.6
Chad	2 300	0.1
Mali	2 200	0.1
North Korea	1 700	1.6
Yemen	1 300	0.9
DR Congo	800	0.1

Source: carbon data: https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

Table 8.7 PPP and carbon emissions

Figure 8.4 shows the relationship between PPP and carbon footprint.

Figure 8.4 shows the relationship between PPP and carbon footprint.

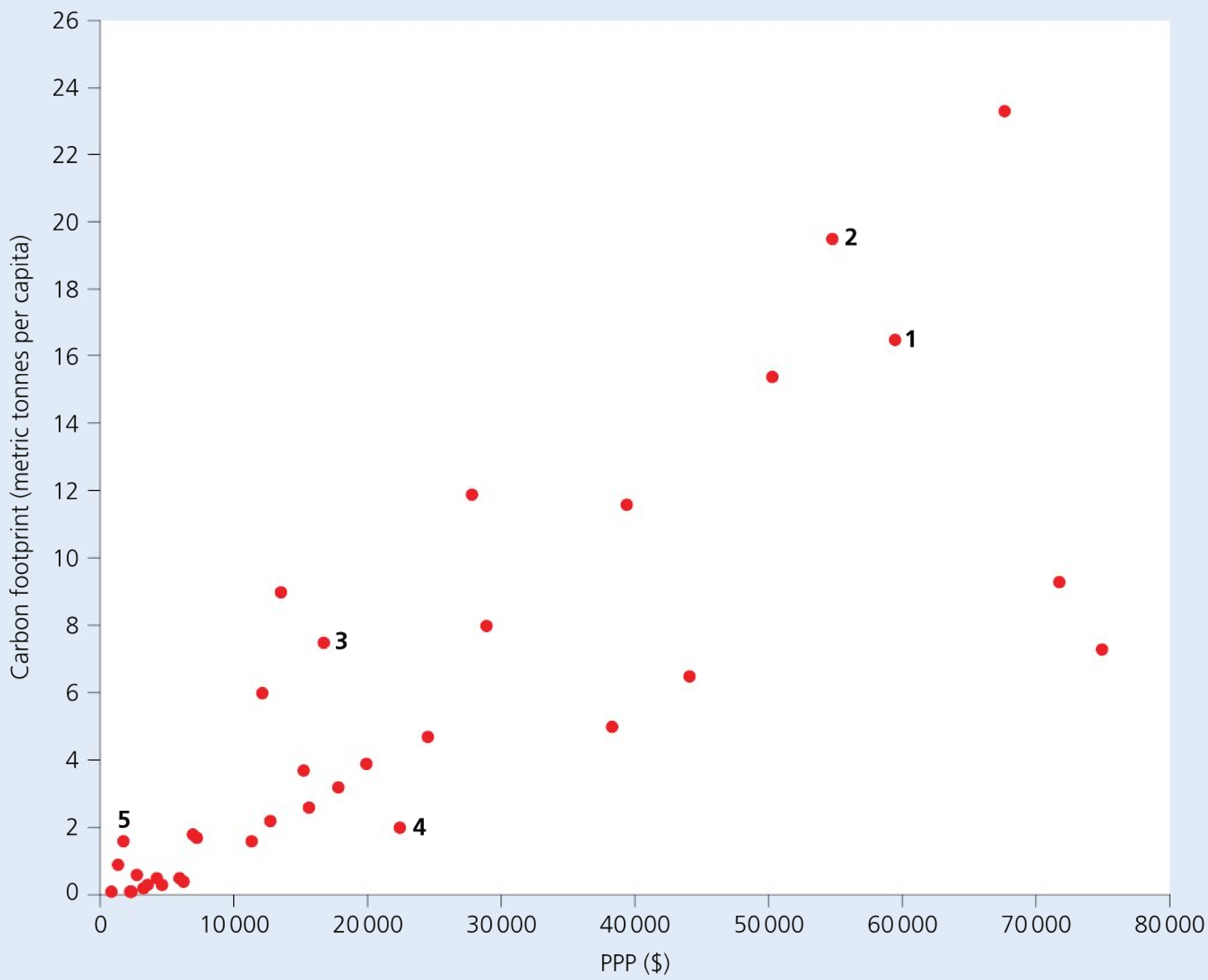


Figure 8.4 Scatter graph showing the relationship between PPP and carbon footprint

a Identify the countries numbered 1–5.

b Calculate Spearman's rank correlation coefficient for the relationship between PPP and carbon footprints. State the level of statistical significance.

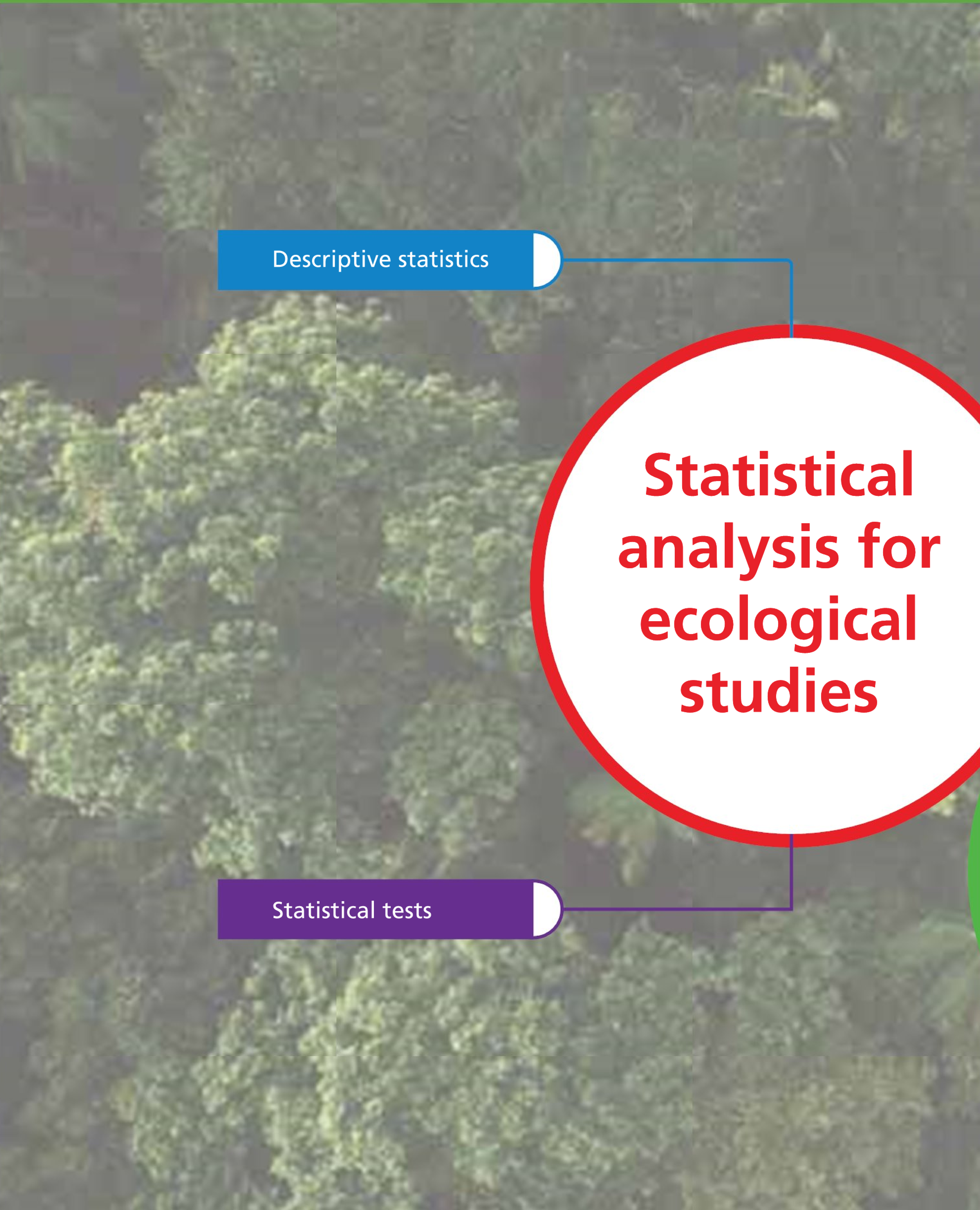
Ideas for investigations

- Investigate the relationship between development indicators, for example, PPP, GNI and environmental impact (such as water footprint, carbon footprint and/or ecological footprint).
- Investigate the ecological footprint of your school, college or home.
- Investigate the relationship between population growth and consumption of plastic.
- Investigate the relationship between level of income and the disposal of solid domestic waste.

ENVIRONMENTAL ISSUES

Population growth has many environmental impacts, such as those on food supply, pollution, energy use and so on. However, even when population growth slows down, there is significant environmental impact. This is referred to as **over-consumption**, that is, richer nations (with less population growth) consume more resources per person than poorer countries (which may have more rapid population growth).

Analytical



Descriptive statistics

Statistical analysis for ecological studies

Statistical tests

skills

Information communication technology

- Spreadsheets and databases
- Data logging
- Smartphones
- Simulations
- Coding

Secondary demographic, development and environmental data

- Census data
- National Statistics
- Geographical information systems
- Environment Agency data
- Living Planet Report
- Meteorological Office data

9 Statistical analysis for ecological studies

Introduction

Data in ecological studies are usually complex and trends unclear. Statistical techniques allow data to be analysed and underlying patterns revealed.

Tabulating raw and processed data, drawing line graphs, calculating values such as mean, median, mode and standard deviation are all referred to as **descriptive statistics** and are useful for summarizing data and for assessing the variation in samples and sets of replicates. Their use helps to identify trends and draw conclusions from the data. Error bars in graphs, representing, for example, standard deviation or standard error (see page 124), show the variability of data around a mean and indicate uncertainty in the data.

Statistical tests, sometimes called **inferential statistics**, such as the chi-squared and *t*-test, involve complex calculations that allow differences to be compared between experimental treatments or samples, to see if they are likely to have occurred as a result of variation in the data or if they are a treatment effect.

If the statistics show a treatment effect, then the results are said to be statistically significant. A statistically significant result is one where there is a less than 5% probability that it has occurred by chance alone.

Normal distribution

Data obtained from biological experiments may show a 'normal distribution' – this means that when the frequency of particular classes of measurements is plotted against the classes of measurements, a symmetrical bell-shaped curve is obtained (Figure 9.1).

Normal distribution curve

Most biological data show variability, but with values grouped symmetrically around a central value.

Here the mode, median and mean coincide.

Skewed distribution curve

Values reduce in frequency more rapidly on one side of the most frequently obtained value than on the other.

Here the difference between the mean and mode is a measurement of 'skewness' of the data.

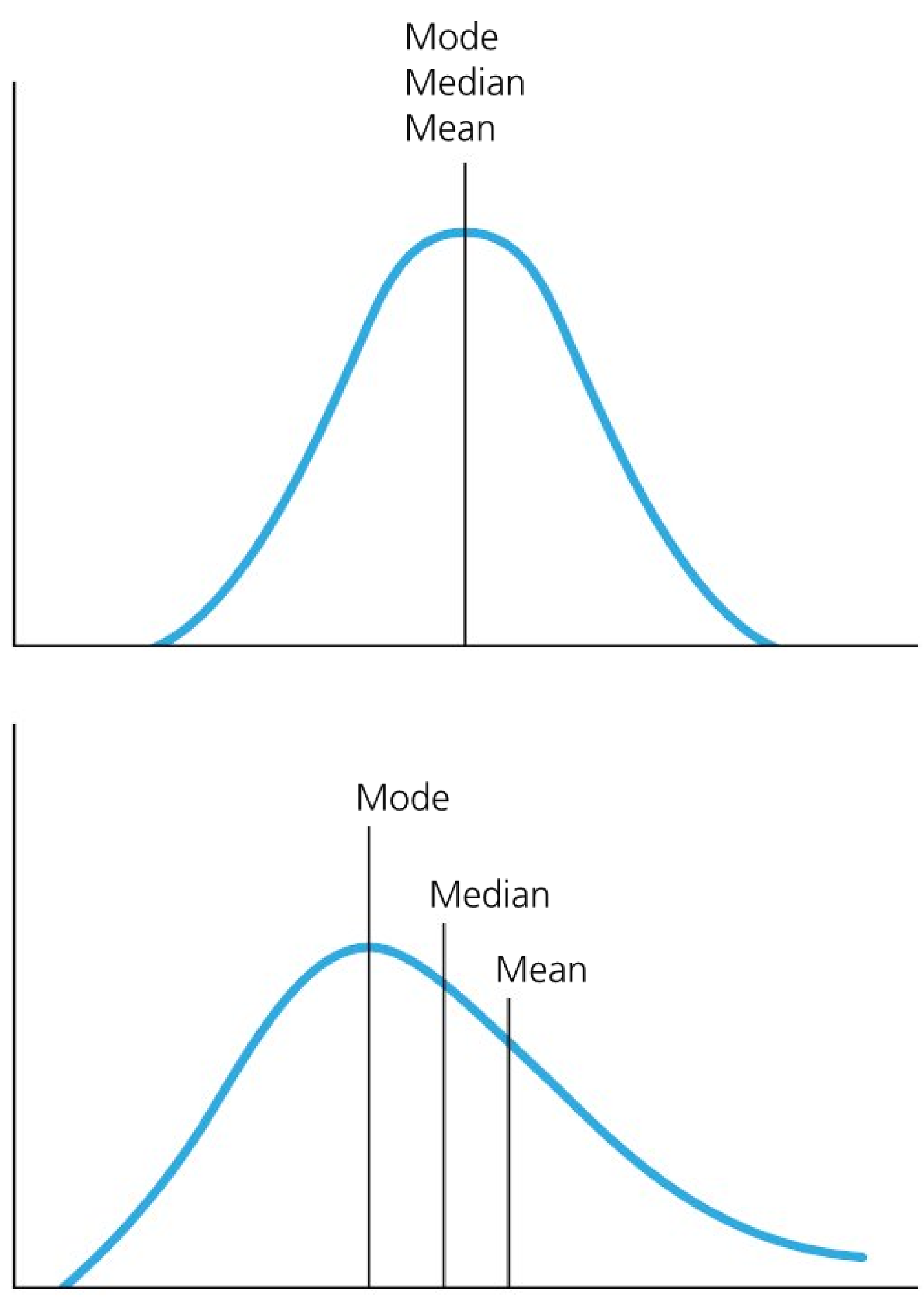


Figure 9.1 Frequency distributions of normal and skewed (non-normal) data

Expert tip

You can use the range for data that are not normally distributed to show an estimate of the deviation of values from the mean.

An example of a normal distribution is the number of humans at any particular height plotted against their different height classes, arranged in ascending order (Figure 9.2).

For the purpose of the graph, the heights are collected into arbitrary groups, each with a height range of 2 cm.

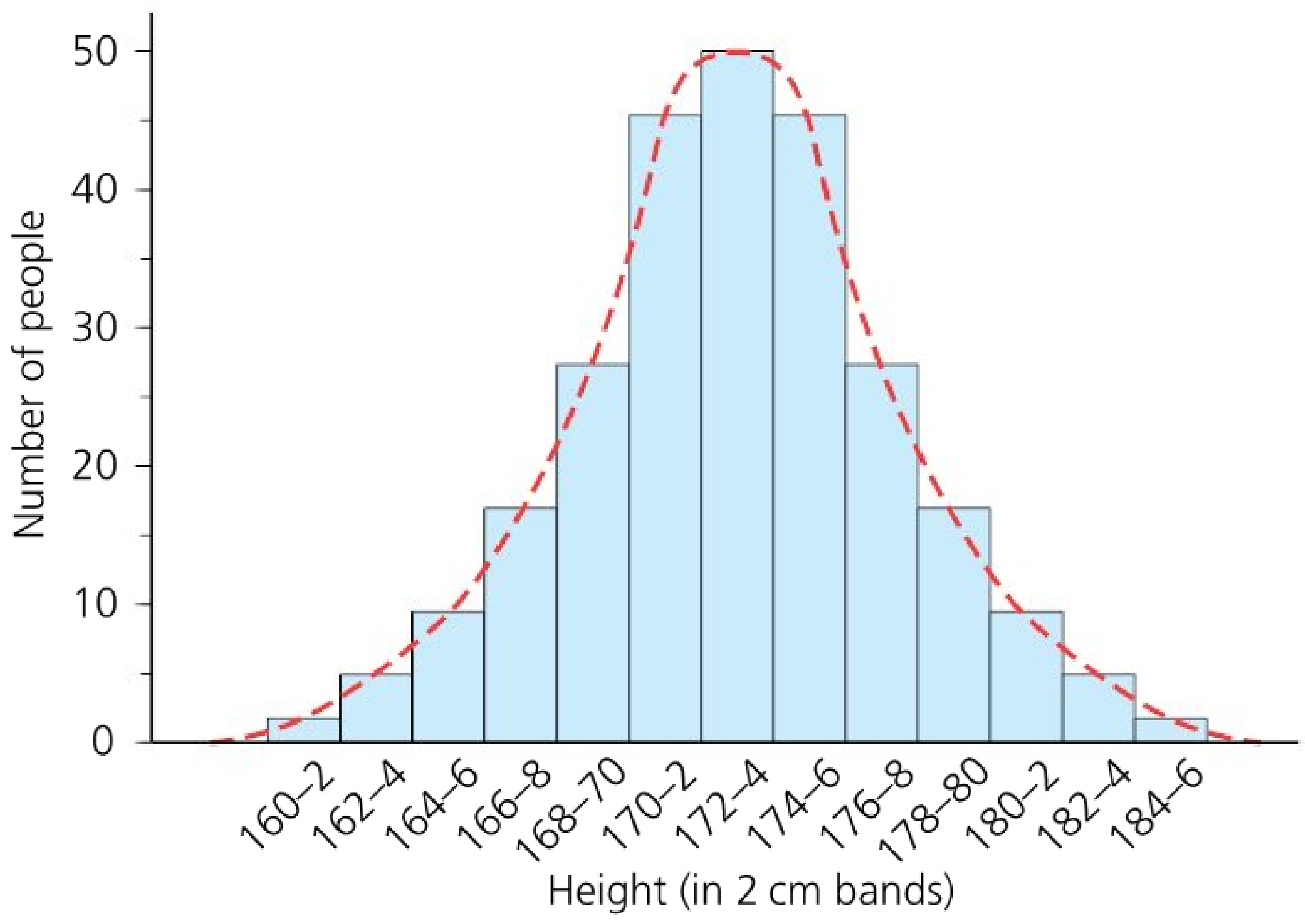


Figure 9.2 Histogram of human height data (blue bars) approximate a normal distribution. The true normal distribution is indicated by the dotted red line, in which the measurement (height) can vary continuously and is not sorted into classes

Descriptive statistics: mode, median and mean

The normal distribution shows symmetrical distribution of data around the central tendency (a central value for a probability distribution). There are three different ways of calculating the central tendency:

- The **mode**: the most frequent value in a set of values.
- The **median**: the middle value in a set of values arranged in ascending order. If there are an even number of items in a data set, then the median is found by taking the average (mean) of the two middlemost numbers.
- The average or arithmetic **mean**: calculated by dividing the sum of the individual values by the number of values obtained. The formula for the arithmetic mean is:

$$= \frac{\Sigma x}{n}$$

where

x = the arithmetic mean

Σx = the sum of all the measurements

n = the total number of measurements

Expert tip

The mode is not typically used as a measure of central tendency in environmental studies but it can be useful in describing a bimodal distribution, which has two peaks or modes. It can be caused by disruptive selection.

Standard deviation

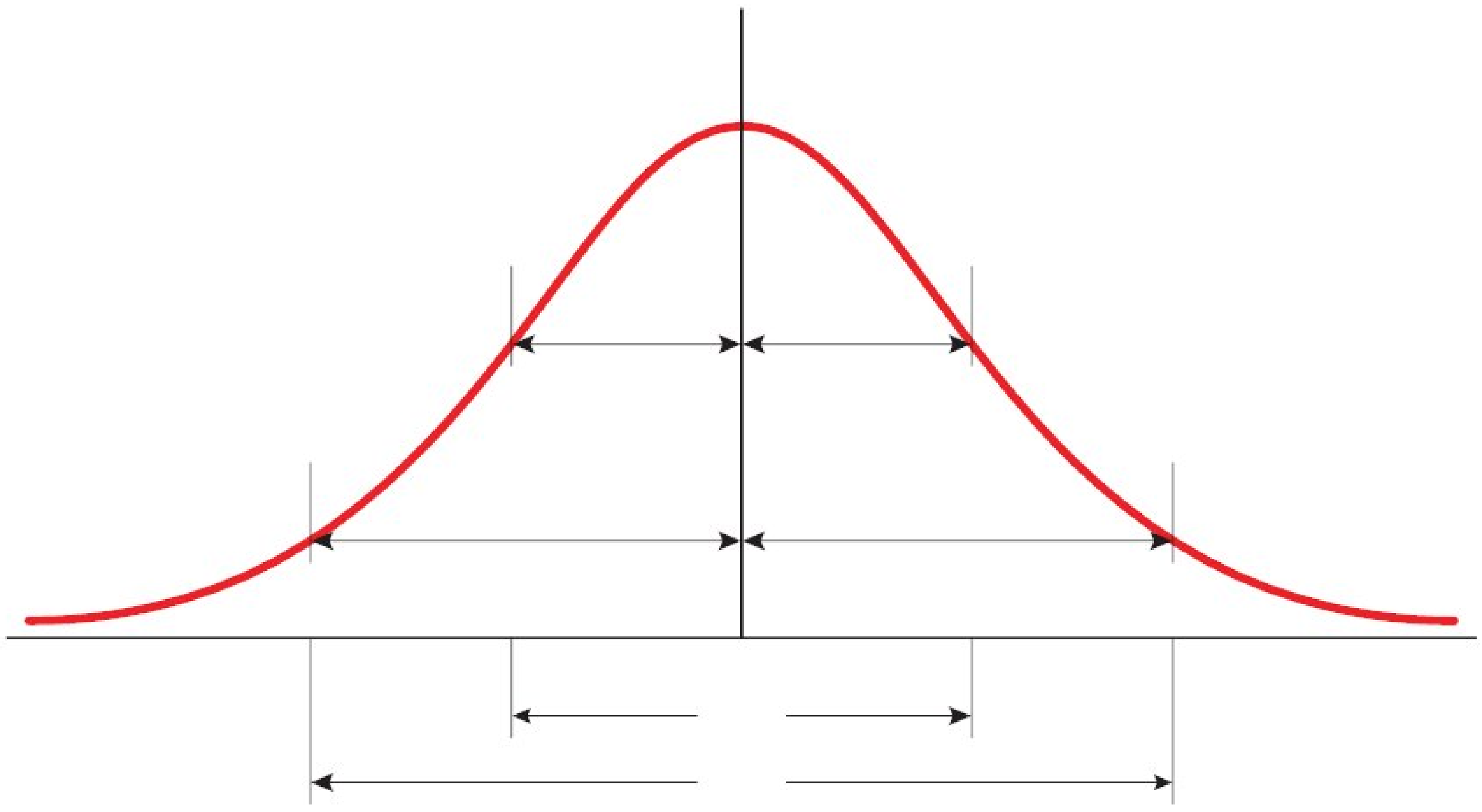
Standard deviation from the mean measures how spread out data are from the central tendency. It is a measure of the variation from the mean of a set of values.

- A small standard deviation indicates that the data is clustered closely around the mean value.
- A large standard deviation indicates a wider spread around the mean.

Once obtained, the value may be applied to the normal distribution curve (Figure 9.3). Note that 68% of the data occurs within one standard deviation of the mean and more than 95% of the data occurs within two standard deviations of the mean. So, a small standard deviation indicates that the observations (the values) differ very little from the mean.

Key definition

Standard deviation – the spread of a set of data from the mean of the sample is a measure of the variability of a population from a sample.



Fruit production in *Ranunculus acris*

Values obtained in ascending order x	Frequency f	fx	Deviation of x from the mean $(x - \bar{x})[= d]$	d^2	fd^2
18	1	18	–12	144	144
19	1	19	–11	121	121
20	1	20	–10	100	100
21	1	21	–9	81	81
22	1	22	–8	64	64
23	3	69	–7	49	147
24	4	96	–6	36	144
25	4	100	–5	25	100
26	5	130	–4	16	80
27	5	135	–3	9	45
28	6	168	–2	4	24
29	8	232	–1	1	8
30	14	420	0	0	0
31	12	372	1	1	12
32	10	320	2	4	40
33	7	231	3	9	63
34	3	102	4	16	48
35	2	70	5	25	50
36	3	108	6	36	108
37	2	74	7	49	98
38	3	114	8	64	192
39	2	78	9	81	162
40	2	80	10	100	200
	$\Sigma f = 100$	$\Sigma fx = 2999$			$\Sigma fd^2 = 2031$

Mean of data $= \dfrac{\Sigma fx}{\Sigma f} = \dfrac{2999}{100} = 29.99$

$$\text{SD} = \sqrt{\left(\frac{\Sigma fd^2}{\Sigma f - 1}\right)} = \sqrt{\frac{2031}{99}} = \sqrt{20.51} = 4.53$$

Thus the mean of the sample *Ranunculus acris* = 29.99, and the SD = 4.53.

Table 9.2 Calculating the means and standard deviations of the data in Table 9.1

Fruit production in *Ranunculus repens*

Values obtained in ascending order x	Frequency f	fx	Deviation of x from the mean $(x - \bar{x})[= d]$	d^2	fd^2
16	1	16	–9	81	81
17	1	17	–8	64	64
18	2	36	–7	49	49
19	4	76	–6	36	72
20	4	80	–5	25	100
21	8	168	–4	16	64
22	7	154	–3	9	72
23	9	207	–2	4	28
24	10	240	–1	1	9
25	16	400	0	0	0
26	9	234	1	1	16
27	10	270	2	4	36
28	4	112	3	9	90
29	5	145	4	16	64
30	3	90	5	25	125
31	1	31	6	36	108
32	1	32	7	49	49
33	2	66	8	64	64
34	1	34	9	81	162
35	1	35	10	100	100
36	1	36	11	121	121
	$\Sigma f = 100$	$\Sigma fx = 2479$			$\Sigma fd^2 = 1474$

Mean of data $= \dfrac{\Sigma fx}{\Sigma f} = \dfrac{2479}{100} = 24.79$

$$\text{SD} = \sqrt{\left(\frac{\Sigma fd^2}{\Sigma f - 1}\right)} = \sqrt{\frac{1474}{99}} = \sqrt{14.89} = 3.86$$

Thus the mean of the sample *Ranunculus repens* = 24.79, and the SD = 3.86.

Table 9.3 Calculating the means and standard deviations of the data in Table 9.1

Standard error

The **standard error** (S_M) represents how well the sample mean approximates to the population mean. The larger the sample, the smaller the standard error, and the closer the sample mean approximates to the population mean. The standard error is obtained by dividing the standard deviation, s, by the square root of n, the sample size:

$$S_M = \frac{s}{\sqrt{n}}$$

Common mistake

A common misconception is that standard deviation decreases with increasing sample size. Standard deviation can either increase or decrease as sample size increases; it depends on the measurements in the sample. If there is a lot of variation in a population, the standard deviation will be large.

When graphs are presented showing mean values, error bars are added to each value plotted to demonstrate the deviation of the sample from the true population mean. Error bars ($\pm 1S_M$) extend above and below the points plotted on a graph to show this variability (Figure 9.4a). Non-overlapping error bars demonstrate that the difference between mean values is significant (as shown in Figure 9.4a), whereas overlapping error bars would suggest a non-significant difference.

> **Key definition**
>
> **Standard error** – an estimate of the reliability of the mean of a population sample. A small standard error indicates that the mean value is close to the actual mean of the population.

	Standard deviation, *s*	$\frac{s}{\sqrt{n}}$	**Standard error, S_M**
R. acris	4.53	$\frac{4.53}{10}$	0.453
R. repens	3.86	$\frac{3.86}{10}$	0.386

Table 9.4 Calculating the standard errors (S_M)

In an experiment on the effect of anaerobic pre-treatment of tissue discs on their subsequent change in mass, samples of ten thin discs of plant tissue were used. (Thin cut discs allow all cells in a sample to receive more or less identical conditions.) The results of this inquiry indicated that anaerobic pre-treatment of the discs leads to a gain in mass. Error bars have been added to the curve in this graph (Figure 9.4b).

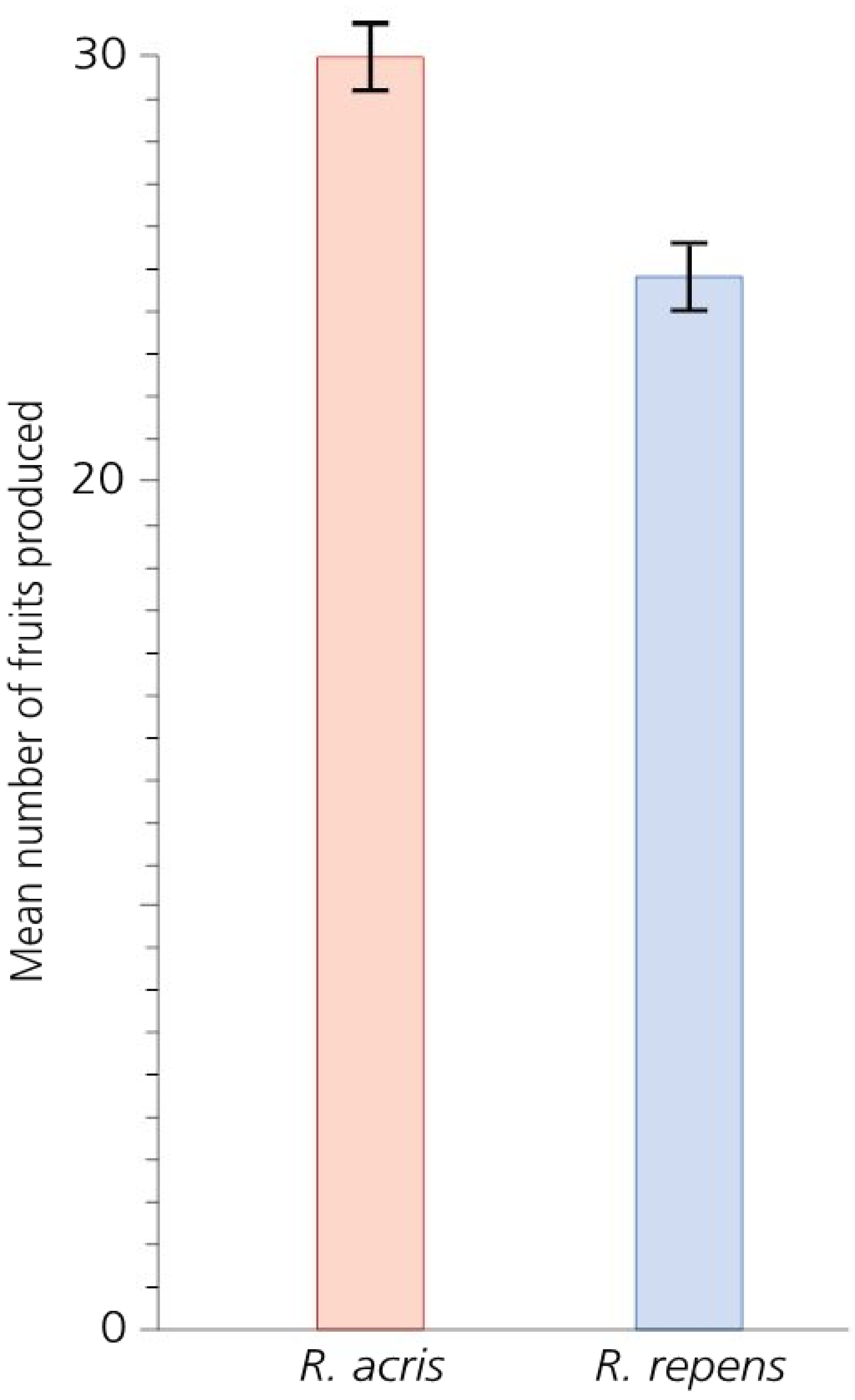


Figure 9.4a Adding standard errors to a display of the means

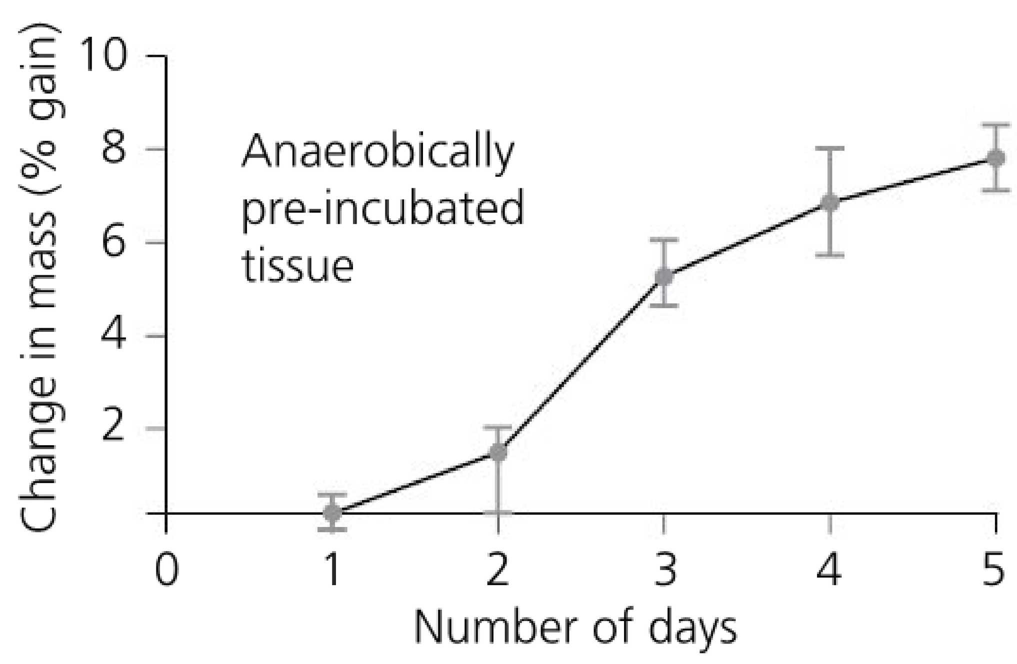


Figure 9.4b An example of the addition of error bars to a graph

Inferential statistics

Statistical tests

All ecological statistical techniques involve hypothesis-testing and test a statement called the **null hypothesis**. Statistical analyses test whether data matches the null hypothesis or significantly varies from it. Where data are being compared, the null hypothesis states that *there is no difference between the sets of data*, and when an association is being investigated it states that *there is no association*. The **hypothesis** is the opposite of the null hypothesis, that is, that there *is* a difference or association shown by the data.

Because of the complexity of the data, ecologists can never be 100% certain that their results are true or not – statistical tests allow them to be 95% certain that any associations or correlations found in the data are real and not due to chance (that is, there is a 5% chance that they *are* due to chance). The outcome of a statistical test is therefore a *probability* that the null hypothesis is true. A probability (known as the ***p* value**) varies from 0 (impossible) to 1 (certain). Since the p values are small, they are given as a percentage (0 to 100%) to avoid possible confusion with small numbers. The lower the probability, the less likely it is that the null hypothesis is true.

One statistical test, known as the t-test (see Worked example on page 127), compares the means of data to test for significant differences between the samples. For the -test, the null hypothesis is *There is no difference between the means of two samples*. By convention, the **5% significance level** (also known as the **95% confidence level**) is used, that is, if the probability is greater than 0.05 (5%) then the null hypothesis is accepted. However, if the probability is 0.05 or less ($p < 0.05$), then the null hypothesis is rejected. This implies the event is predicted to happen by chance less than once in twenty times. So the difference is judged to be significant.

Charts of statistical probability are used to determine whether a result is significant or not (Figure 9.5). These present long series of data, at different levels of probability depending on sample size, to which the results of a statistical test are compared. These **critical values** are compared to the result of the statistical test – in general, if the result is greater than the critical value (the Mann–Whitney U test is an exception) then the null hypothesis is rejected and the hypothesis accepted. Sample size is represented in the tables of critical values as degrees of freedom (df). In the t-test, for example, degrees of freedom are determined by the number of samples there are in each data set, using the formula:

$$\mathrm{df} = (n_1 - 1) + (n \ - 1)$$

where

n = the number of samples in the first sample

n_2 = the number of samples in the second sample

Each statistical test has a different method for determining degrees of freedom, although all are based on the number of independent observations in a set of data.

Degrees of freedom (df)	Decreasing value of p ⟶			
	p values			
	0.10	**0.05**	**0.01**	**0.001**
1	6.31	12.71	63.66	636.60
2	2.92	4.30	9.92	31.60
3	2.35	3.18	5.84	12.92
4	2.13	2.78	4.60	8.61
5	2.02	2.57	4.03	6.87
6	1.94	2.45	3.71	5.96
7	1.89	2.36	3.50	5.41
8	1.86	2.31	3.36	5.04
9	1.83	2.26	3.25	4.78
10	1.81	2.23	3.17	4.59
12	1.78	2.18	3.05	4.32
14	1.76	2.15	2.98	4.14
16	1.75	2.12	2.92	4.02
18	1.73	2.10	2.88	3.92
20	1.72	2.09	2.85	3.85
22	1.72	2.08	2.82	3.79
24	1.71	2.06	2.80	3.74
26	1.71	2.06	2.78	3.71
28	1.70	2.05	2.76	3.67
30	1.70	2.04	2.75	3.65
40	1.68	2.02	2.70	3.55
60	1.67	2.00	2.66	3.46
120	1.66	1.98	2.62	3.37
∞	1.64	1.96	2.58	3.29

Table 9.5 Critical values for the *t*-test

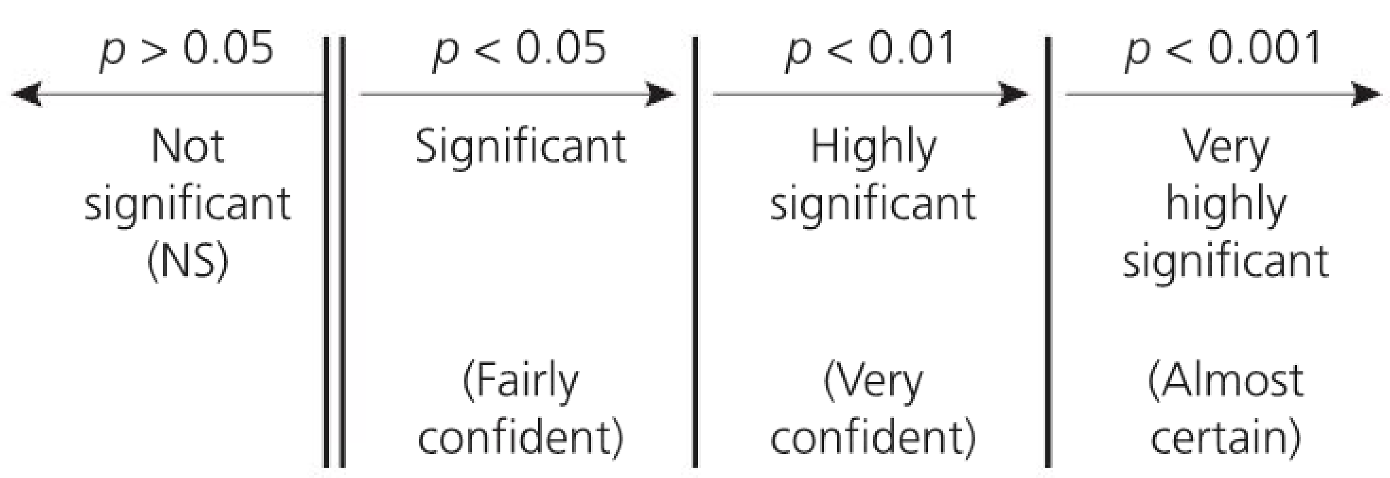


Figure 9.5 Different levels of confidence in statistical tests

Carrying out statistical tests

Statistical tests using standard deviation or standard error typically compare large, randomly selected representative samples of normally distributed data. In practice it is often the case that data can only be obtained from relatively small samples. Different statistical tests are used for different types of data. The -test, for example, may be applied to sample sizes of ideally more than 15 and less than 30 pairs of data taken from normally distributed data, and provides a way of measuring the overlap between two sets of data – a large value of indicates little overlap and makes it highly likely there is a significant difference between the two data sets.

Even though the method for each test is different, the protocol for carrying out statistical tests is the same for each. The following Worked example shows how a statistical test should be presented.

Worked example

Applying the *t*-test

An ecologist was investigating woodland microhabitats, contrasting the communities in a shaded position with those in full sunlight. One of the plants was ivy (*Hedera helix*), but relatively few occurred at the locations under investigation. The following research question was developed: were the leaves in the shade actually larger than those in the sunlight?

Leaf widths were measured but, because the size of the leaves varied with the position on the plant, only the fourth leaf from each stem tip was measured. The results from the plants available are shown in Table 9.6.

Size–class/mm	Widths of leaves from plants in sun (a)	Widths of leaves from plants in shade (b)
20–24	24	
25–29	26, 26	26
30–34	30, 31, 31, 32, 32, 33	33, 34
35–39	37, 38	35, 35, 36, 36, 36, 37
40–44	43	41, 42
45–49		45

Table 9.6 Widths of leaves of *Hedera helix* in sun and shade

1 The null hypothesis assumes the difference under investigation has arisen by chance, that is, there is no difference in width between leaves from plants growing in sun and shade. The role of this statistical test is to determine whether to accept or reject the null hypothesis. If it is rejected in this case, we can have confidence that the difference in the leaf sizes of the two samples is statistically significant.

2 Check that the data is approximately normally distributed. This is done by arranging the data for the two samples and plotting a histogram. (An example of a histogram is shown in Figure 9.2 on page 121.)

3 The formula for the *t*-test for unpaired samples (data sets 'a' versus 'b') is:

$$t = \frac{\bar{x}_a - \bar{x}_b}{\sqrt{\left(\frac{s_a^2}{n_a} + \frac{s_b^2}{n_b}\right)}}$$

where

$\bar{x}_a$ = the mean of data set a

$\bar{x}_b$ = the mean of data set b

s_a^2 = the standard deviation of data set a, squared

s_b^2 = the standard deviation of data set b, squared

n_a = the number of data items in set a

n_b = the number of data items in set b

4 Once a value of *t* has been calculated (the value of *t* in this case is 2.10), a table of critical values for the *t*-test needs to be consulted, once the degrees of freedom (df) for the two samples have been determined using the formula: $(n_a - 1) + (n_b - 1)$ (see page 125). In this case, there are 11 + 11 = 22 degrees of freedom.

5 A table of critical values for the *t*-test is given in Figure 9.5 on page 126. The column of significance levels (*p*) at the 0.05 level is read until the line corresponding to 22 degrees of freedom is reached. In this case, *p* = 2.08.

6 Since the calculated value of *t* (2.10) exceeds this critical value (2.08) at the 0.05 level of significance, it indicates that there is a lower than 0.05 probability (5%) that the difference between the two means is solely due

to chance. Therefore, the null hypothesis can be rejected, and it can be concluded that **the difference between the two samples is significant**. (*Note:* the significance of this statistic suggests there is a reason for the difference in the means. This can be further investigated and perhaps a fresh hypothesis proposed.)

Expert tip

Scientific experiments often consist of comparing two or more sets of data. This data is described as unpaired or independent when the sets of data arise from separate individuals, and paired when it arises from the same individual at different points in time.

The unpaired *t*-test, for example, tests the null hypothesis that the population means related to two independent, random samples from an approximately normal distribution are equal.

Expert tip

A statistically significant result is one that is unlikely to be due to chance alone. Confidence intervals or error bars are used to indicate the variability of data around a mean. If the treatment average differs from the control average sufficiently for their confidence intervals not to overlap then the data can be said to be different.

Selecting the correct statistical test

Different statistical tests are used to analyse different types of data. Table 9.7 outlines the different tests available and how they should be used. Figure 9.6 (on page 129) can be used to select the correct statistical technique.

Statistical test	When to use it	Criteria for using test	How to interpret the value that is calculated
-test	You want to know if two sets of continuous, normally distributed data are significantly different from one another.	Ideally you have two sets of continuous data with >15 but <30 readings for each set of data. Both sets of data are from populations that have normal (Gaussian) distributions with similar standard deviations.	Use a *t*-test table to look up the value of . If this is greater than the value for a probability of 0.05 then you can state that the two populations are significantly different.
Mann–Whitney *U*	You want to know if two sets of continuous, non-normally distributed data are significantly different from one another.	Ideally you have two sets of continuous data for 6–20 pairs of data. Both sets of data do **not** have normal distributions (that is, are skewed).	*U* is calculated for each set of data. The lowest value of *U* is used as your test statistic. Use a Mann–Whitney *U* table to look up the value of *U*. If this is **less than** or equal to the *U* value for a probability of 0.05 then you can state that the two populations are significantly different.
Chi-squared test	You want to know if your observed results differ significantly from your expected results.	You have two (or more) sets of nominal, categorical data.	Use a χ^2 table to look up the value of χ . If this value is greater than the χ^2 value for a probability of 0.05, then you can state that your observed results differ significantly from your expected results.
Pearson correlation coefficient	You want to know if there is a linear correlation between two paired sets of data.	You have two sets of interval data. At least 10 pairs of data, ideally more than 25. A scatter graph suggests there might be a linear relationship and both sets of data have an approximately normal distribution.	A value close to +1 indicates a positive linear correlation. A value close to –1 indicates a negative/inverse linear correlation. A value close to 0 indicates no correlation.
Spearman's rank	You want to know if there is a correlation (not necessarily linear) between two paired sets of data.	You have quantitative data that can be ranked. The samples for each set of data were made randomly. You have at least 10 pairs of data but ideally between 10 and 30. A scatter graph suggests there might be a linear relationship.	Use a correlation table to look up the value of *r* . If the value of *r* is greater than the r_s value for a probability of 0.05, you can state there is a significant correlation between the two values.

Table 9.7 The use of different statistical tests

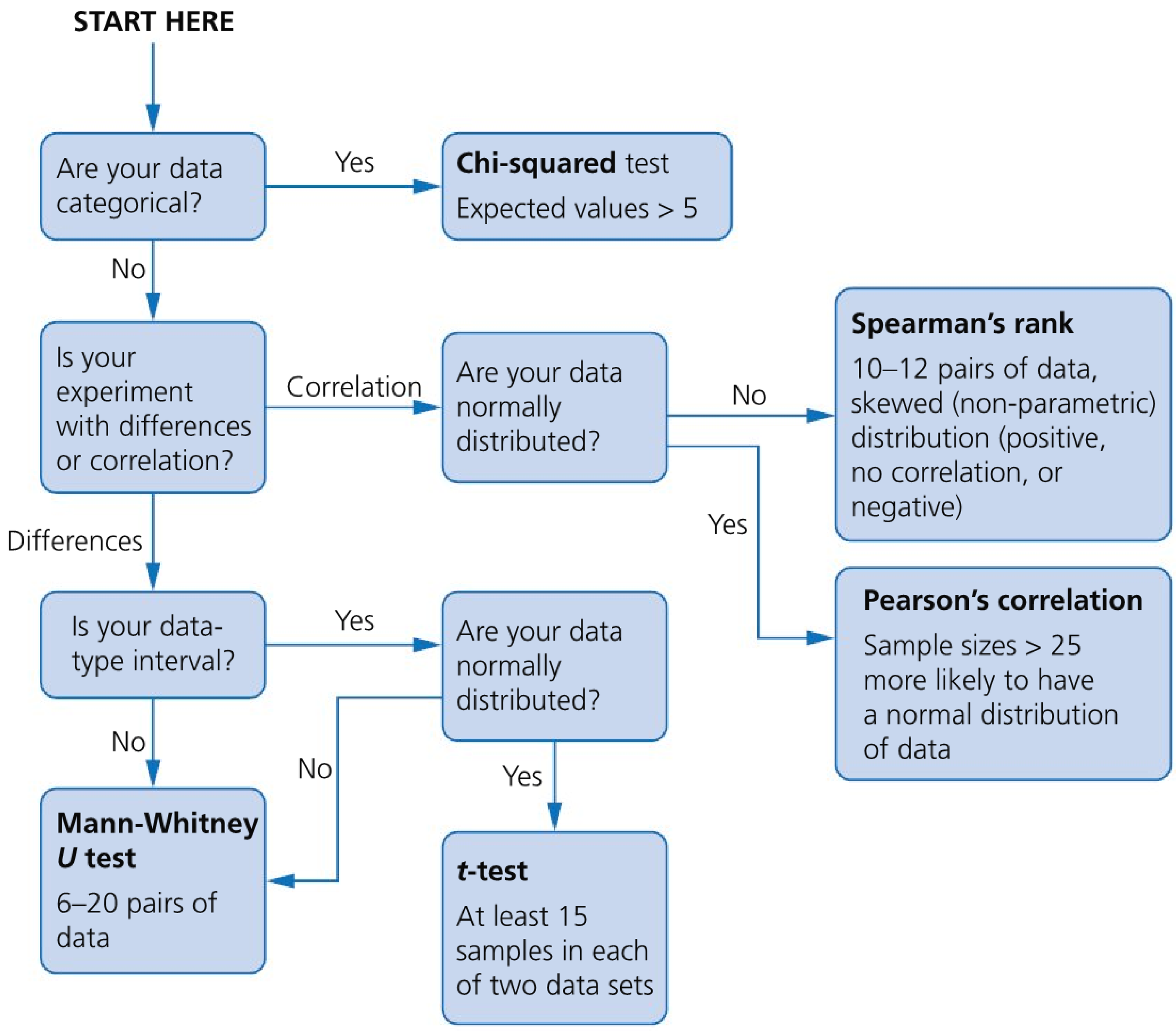


Figure 9.6 Key for identifying the correct statistical test

The application of the *t*-test has been described previously (page 127). The other tests may be useful in your IA, although you will not be expected to use or calculate them in an examination. Many calculators are programmed to carry out statistical tests, and computers can run spreadsheet programs with programmed statistical tests (see Chapter 10, pages 137–138). Dedicated statistical software is also available. The following sites can be used to carry out statistical tests:

- Mann–Whitney *U*: **http://scistatcalc.blogspot.co.uk/2013/10/mann-whitney-u-test-calculator.html**
- *t*-test: **http://www.physics.csbsju.edu/stats/t-test_bulk_form.html**
- Spearman's rank: **http://mathematics.laerd.com/maths/spearmans-rank-order-correlation-calculator.php**
- Chi-squared test: **http://www.socscistatistics.com/tests/chisquare2/Default2.aspx**
- Pearson's correlation: **http://www.socscistatistics.com/tests/pearson/Default2.aspx**

Expert tip

Students are often concerned about the use of statistics to analyse data. The mathematics that underpins statistics can be complex and difficult to understand. However, when analysing results of practical investigations, it is more important to show an appreciation of what the statistics can do or show, rather than how they work.

Correlation coefficient

The Pearson correlation coefficient (r) measures the strength and the direction of a linear relationship between two variables. The value of r lies between –1 and +1 (Figure 9.7). The + and – signs are used to indicate positive linear correlations and negative linear correlations, respectively.

Positive correlation: if x and y have a strong positive linear correlation, r is close to +1. An value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between x and y variables such that as values for x increases, values for y also increase.

Expert tip

Interval data is data that involves counts; categorical data is data that can be divided into categories.

Expert tip

When researching the techniques to use in your experimental design (methodology) for an IA you should also identify what statistical tests will be used later to analyse the raw data.

Expert tip

Do not choose an investigation solely on the basis that it will involve a statistical test you know and are confident in carrying out. Choose an investigation based on a topic you are interested in.

Negative correlation: if x and y have a strong negative linear correlation, r is close to –1. An r value of exactly –1 indicates a perfect negative fit. Negative values indicate a relationship between x and y such that as values for x increase, values for y decrease.

If there is no linear correlation or a weak linear correlation, r is close to 0. A value near zero means that there is a random, non-linear relationship between the two variables.

A perfect correlation of ±1 occurs only when the data points all lie exactly on a straight line. If r = +1, the slope of this line is positive but if   = –1, the slope of this line is negative.

Examiner Guidance

r is a dimensionless quantity; that is, it does not depend on the units used.

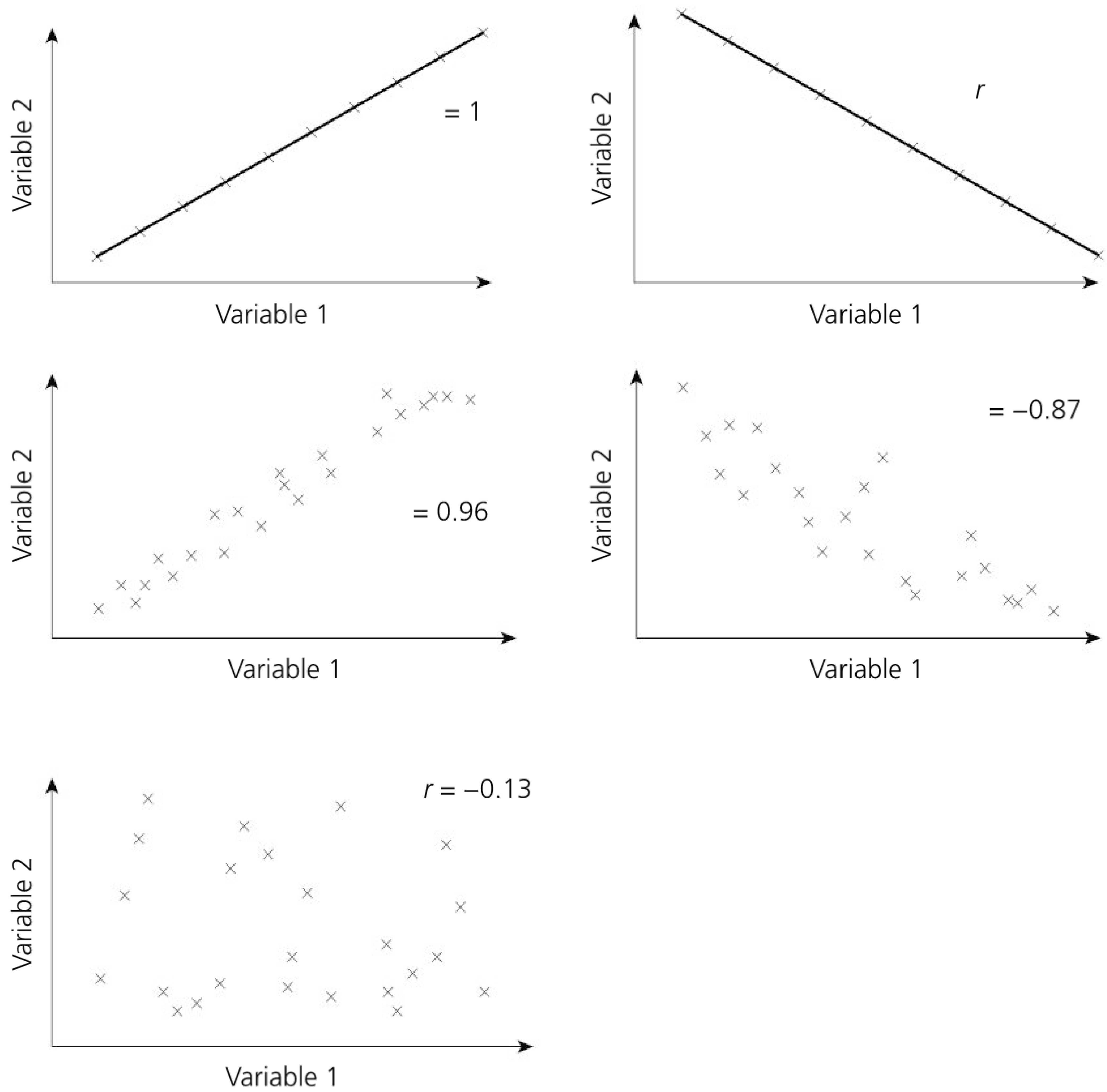


Figure 9.7 The strength of the correlation in the scatter graphs is the correlation coefficient which extends from +1 to –1

A causal relation between two variables exists if changes in one variable causes changes in the other. The first variable can be called the cause and the second the effect. A correlation between two variables does not imply causation.

Expert tip

The Pearson correlation coefficient measures the strength of the linear relationship between normally distributed variables. When the variables are not normally distributed or the relationship between the variables is not linear, it is more appropriate to use the Spearman rank method.

Further statistical tests

Mann–Whitney *U*

This test is used for investigating the difference between two sets of values from a small data set which may not be normally distributed. The test is carried out in the following way:

Values for the two sets of data are entered into a table:

Data set 1									
Data set 2									

Table 9.8

Both sets of data are then reorganized in a new table and values ranked. Data are ranked together, from lower to higher values, from both sets of values together (see Worked example, page 132) rather than independently (as with the Spearman's rank test – see page 133):

	Rank																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Data set 1																		
Rank (R_1)																		
Data set 2																		
Rank (R_2)																		

Table 9.9

The ranks are totalled for each data set (that is, added together):

- ΣR_1 is the sum or ranks for data set 1
- ΣR_2 is the sum of ranks for data set 2

U values are then calculated using the following formulas:

- U for data set 1:

$$U_1 = (n_1 \times n_2) + \frac{n_2(n_2 + 1)}{2} - \Sigma R_2$$

- U for data set 2:

$$U_2 = (n_1 \times n_2) + \frac{n_1(n_1 + 1)}{2} - \Sigma R_1$$

where

n_1 is the number samples in data set 1

n_2 is the number samples in data set 2

Check the calculation:

$U_1 + U_2 = n_1 \times n_2$

(that is, values for U_1 and U_2 when added together should equal the value of n_1 multiplied by n_2)

The **lowest** value of U is selected as the test statistic.

The test statistic is compared against the table of critical values for Mann–Whitney U:

***p* = 0.05**		**Values of n_2**									
		1	2	3	4	5	6	7	8	9	10
Values of n_2	1										
	2								0	0	0
	3					0	1	1	2	2	3
	4				0	1	2	3	4	4	5
	5			0	1	2	3	5	6	7	8
	6			1	2	3	5	6	8	10	11
	7			1	3	5	6	8	10	12	14
	8		0	2	4	6	8	10	13	15	17
	9		0	2	4	7	10	12	15	17	20
	10		0	3	5	8	11	14	17	20	23

Table 9.10 Critical values for Mann–Whitney *U*

Unlike other test statistics, the null hypothesis is rejected if the test statistic is **less than or equal** to the critical value.

Worked example

An ecological investigation tested whether human trampling affects the height of a shingle ridge plant species, viper's bugloss (*Echium vulgare*).

Plants were measured in a trampled site and an enclosure plot where there was no disturbance (a fenced-off area of the shingle ridge where there was no access for the public). Plant height was measured using a ruler (in cm).

Hypothesis: there is a significant difference in the height of viper's bugloss in the trampled and untrampled areas.

Null hypothesis: there is no significant difference in the height of viper's bugloss in the trampled and untrampled areas.

Data from both sites were collected and ranked:

n	Height of plant in trampled area/cm	Height of plant in untrampled area/cm	Rank 1 (R_1)	Rank 2 (R_2)
1	0.0	51.3	3	12
2	0.0	86.2	3	20
3	31.6	0.0	9	3
4	51.0	67.8	11	16
5	52.2	74.2	13	18
6	25.9	71.0	7	17
7	0.0	21.4	3	6
8	31.1	55.7	8	14
9	0.0	66.7	3	15
10	46.3	85.6	10	19
		Sum of ranks	**70**	**140**

Table 9.11

U values for each of the two sets of data were calculated:

$$U_1 = (n_1 \times n_2) + \frac{n_2(n_2 + 1)}{2} - \Sigma R_2$$

$$= 10 \times 10 + \frac{10(10 + 1)}{2} - 140$$

$$= 100 + (55 - 140)$$

$$= \mathbf{15}$$

$$U_2 = (n_1 \times n_2) + \frac{n_1(n_1 + 1)}{2} - \Sigma R_1$$

$$= \mathbf{10} \times \mathbf{10} + \frac{10(10 + 1)}{2} - \mathbf{70}$$

$$= 100 + (55 - 70)$$

$$= \mathbf{85}$$

The lower U value, 15, becomes the test statistic. This value is then compared to the table of critical values at the 5% significance level. With 10 pairs of data, the critical value is 23.

The null hypothesis is rejected because the test statistic is lower than the critical value (15 < 23). There is therefore a significant difference in the height of viper's bugloss plants in the trampled and undisturbed sites.

■ Spearman's rank

Spearman's rank correlation coefficient is a statistical test which can be used to determine the strength and direction (negative or positive) of a relationship between two variables. The result will always be between +1 (strong positive correlation) and –1 (strong negative correlation). In this test, data for two variables are ranked independently, the differences between paired ranked values are calculated, and these values are used to determine Spearman's rank coefficient. If paired values are identically ranked, Spearman's rank will be equal to +1, indicating a perfect correlation. For values <1, a table of critical values can be used to determine whether a correlation is significant or not.

The equation for Spearman's rank is:

$$r_s = 1 - \frac{6\sum\ ^2}{(n^2 \quad 1)}$$

where

r_s = Spearman's rank correlation coefficient

d = differences between ranks of the two sets of data

d^2 = square of difference between ranks

n = number of pairs of data.

Worked example

An investigation was carried out into the relationship between soil depth and plant height along a coastal shingle ridge succession. Samples were taken every 10 m along a transect perpendicular to the sea. Soil depth was measured at the same location as plant height. The tallest plant at each location was selected – the plant was held upright and the height recorded using a tape measure.

Ten pairs of data, of soil depth and plant height, provided sufficient data to carry out the statistical test.

Spearman's rank was used to test whether the correlation between soil depth and plant height is statistically significant.

The following table contains data collected from the investigation. Results show the average values from five transects:

	Transect station number									
	1	2	3	4	5	6	7	8	9	10
Average plant height/cm ± 0.1 cm	24.0	31.0	12.5	44.0	33.0	137.0	242.0	200.0	324.0	250.0
Average soil depth/cm ± 0.1 cm	0.0	2.0	14.3	19.9	19.0	35.0	40.0	40.5	81.5	24.0

Table 9.12 Data from a shingle ridge succession investigating the effect of soil depth on plant height

Station 1 is nearest the sea and 10 furthest from it.

Null hypothesis: there is no significant correlation between soil depth and plant height.

Spearman's rank is calculated in the following way:

$$_s = 1 - \frac{6\sum d^2}{n(n}$$

where

d = the difference in ranks

n = number of pairs of data

Analysis table for Spearman's rank:

n	Soil depth/cm	Plant height/cm	Rank of soil depth	Rank of plant height	Rank difference (*d*)	Difference² (d^2)
1	0.0	24.0	1	2	1	1
2	2.0	31.0	2	3	1	1
3	14.3	12.5	3	1	2	4
4	19.9	44.0	5	5	0	0
5	19.0	33.0	4	4	0	0
6	35.0	137.0	7	6	1	1
7	40.0	242.0	8	8	0	0
8	40.5	200.0	9	7	2	4
9	81.5	324.0	10	10	0	0
10	24.0	250.0	6	9	3	9
n = 10					**$\sum d^2$ =**	**20**
					$6\sum d^2$ =	**120**
					$n(n^2 - 1)$ =	**990**

Table 9.13 Calculating Spearman's rank for plant height and soil depth data

Spearman's rank, $r = 1 - \frac{120}{990}$

Therefore, $r_s = 0.88$.

When $n = 10$, the critical value for Spearman's rank at 5% probability level = 0.648 (Table 9.14).

n	Critical value of r_s
7	0.786
8	0.738
9	0.683
10	0.648
12	0.591
14	0.544
16	0.506
18	0.475
20	0.450
24	0.409
30	0.364

Table 9.14 Table of critical values for Spearman's rank correlation coefficient at $p = 0.05$ level

As the r value of 0.88 is higher than the critical value of 0.648, the result is significant at the 5% probability level. The null hypothesis can be rejected. There is a significant correlation between plant height and soil depth at $p = 0.05$.

Chi-squared test

The chi-squared (χ^2) test is used to examine data that fall into discrete categories. It tests the significance of the deviations between numbers observed (O) in an investigation and the number expected (E). The measure of deviation, known as chi-squared, is converted into a probability value using a chi-squared table. In this way, it can be decided whether the differences observed between sets of data are likely to be real or, alternatively, obtained just by chance.

Chi-squared is calculated using the following equation:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where

O = observed result

E = expected result

$\sum$ = the sum of

Worked example

An ecologist may want to investigate whether two species tend to be found together or not. Species which tend to be located together may share similar microhabitat requirements – this gives the ecologist useful information about the organisms involved. A statistical test – the chi-squared test – can be used to assess whether there is an association between two species. If the species are non-motile (that is, sedentary) then quadrats can be used to sample the organisms.

Testing the association between two moorland plants

This example examines whether the moorland species bell heather (*Erica cinerea*) and common heather, also known as ling (*Calluna vulgaris*), tend to occur together. Moorlands are upland areas with acidic and low-nutrient soils, where heather plants dominate. Heathers have long woody stems, grow in dense clumps, and have colourful bright flowers.

Null hypothesis: there is no statistically significant association between bell heather and ling in an area of moorland, that is, their distributions are independent of each other.

In order to sample the two species, the presence or absence of each species was recorded in each of 200 quadrats. The quadrats were located at random on a 100 m × 100 m area of moorland. Two 100 m tapes were placed at right angles to each other. Quadrat locations were chosen by using a random-number generator, which gave two random numbers between 1 and 1000 for each location – the numbers 548 and 889, for example, meant that a quadrat was located 54.8 metres along the bottom tape and 88.9 metres along the side tape.

Observed results

	Bell heather present	Bell heather absent	Total
Ling present	89	45	134
Ling absent	31	35	66
Total	120	80	200

Table 9.15 Observed results – the distribution of ling and bell heather

Expected results

Assuming that the two species are randomly distributed with respect to each other, the probability of ling being present in a quadrat is:

$$\frac{\text{column total}}{\text{total number of quadrats}} = \frac{134}{200} = 0.67$$

Similarly, the probability of bell heather being present in a quadrat is:

$$\frac{120}{200} = 0.60$$

The probability of both species occurring together, assuming random distribution between each species, is: 0.60 × 0.67 = 0.40. The number of quadrats in which both species can be expected is therefore 0.40 × 200 = 80.

Having worked out the number of expected quadrats where the species are found together, other expected values can be calculated by subtracting from the totals. For example, the expected number of quadrats with bell heather but no ling is 120 – 80 = 40. Expected values follow the assumption that totals for each row and column do not change, because the relationship shown by the data is assumed to represent the true relative frequency of each species. Full expected results are:

Expected results

	Bell heather present	Bell heather absent	Total
Ling present	80	54	134
Ling absent	40	26	66
Total	120	80	200

Table 9.16 The full expected results

The calculated values can be checked by using the ratios represented in the table of observed results. For example, the expected number of quadrats where there is no ling and no bell heather can be calculated as follows:

Probability of no ling in a quadrat $= \frac{66}{200} = 0.33$

Probability of no bell heather in a quadrat $= \frac{80}{200} = 0.40$

Probability of neither species in a quadrat $= 0.33 \times 0.40 = 0.13$

Number of expected quadrats with neither species present $= 0.13 \times 200 = 26$ (this figure agrees with the estimated value in the table).

Statistical test

Observed and expected results are therefore:

		Bell heather present	Bell heather absent	Total
Ling present	Observed	89	45	134
	Expected	80	54	
Ling absent	Observed	31	35	66
	Expected	40	26	
Total		120	80	200

Table 9.17 Observed (O) and expected (E) distribution of ling and bell heather

Chi-squared is calculated using the formula:

$$\chi^2 = \Sigma \frac{(O - E)^2}{E}$$

Chi-squared in this example

$$= \frac{(89 - 80)}{80} + \frac{(45 - 54)^2}{54} + \frac{(31 - 40)^2}{40} \quad \frac{(35 - 26)}{26}$$

$= 1.01 + 1.50 + 2.03 + 3.12$

$= 7.66$

To find whether this result is statistically significant or not, the value must be compared to a critical value. To locate the critical value, the appropriate degrees of freedom need to be calculated. Degrees of freedom = (number of columns – 1) × (number of rows – 1), and so in this case = (2 – 1) × (2 – 1) = 1.

Degrees of freedom	0.05 level of significance
1	3.84
2	5.99
3	7.81
4	9.49

Table 9.18 Critical values for the chi-squared (χ) test at $p = 0.05$ level

The chi-squared value of 7.66 is larger than the critical value of 3.84, for 1 degree of freedom, at the probability level of p = 0.05 (the 5% probability level).

The null hypothesis is therefore rejected, and the hypothesis is accepted, which is that there is a statistically significant association between bell heather and ling in an area of moorland. The distributions of the two species are not independent of each other and the distribution of one species is associated with the distribution of the other. Because the species are found together more frequently than expected, and found on their own less frequently than expected, data indicate that there is a positive association between ling and bell heather. This suggests that the two species share a common microhabitat, or are influenced by similar biotic or abiotic factors.

10 Information communication technology

Spreadsheets: analysing data with Excel

Computer spreadsheets, such as Microsoft Excel, provide the means to quickly analyse large amounts of data, and to present outcomes as graphs. This section outlines how Excel can be used to analyse data from an investigation.

Performing a calculation

Use an equals sign (=) in front of the formula. For example, if you want to sum the numbers that are in cells A1 through A12, then in an empty cell type =SUM(A1:A12). If you want to write a formula for the expression $\frac{x^2y}{z + w}$ where is in cell A1, y is in cell A2, z is in cell B3, and w is in cell B5, you could write the formula in cell C2 as =A1^2 * A2/(B3 + B5).

Copying a formula

If you have a formula in cell B1 and you want it in cells B2 through B10, then position the cursor in the lower right-hand corner of selected cell B1 until the cursor becomes a black cross. Click and drag from cells B2 through B10. Note that any cells written in the original formula (in cell B1) will be shifted when the formula is copied, unless the cell references are written using $ symbols, such as A2. For example, if B1 contains =2*A1 and you copy B1 to B2, the formula in B2 will be =2*A2.

Built-in functions in Excel

Excel has a number of built-in functions that can be used to process data and carry out statistical analysis (see pages 138–139). The function wizard, *fx*, on the toolbar will bring up a dialogue box where all the built-in functions are listed.

Excel formula	Description of the formula
=SUM(A2:A5)	Find the sum of values in the range of cells A2 to A5.
=COUNT(A2:A5)	Count the number of numbers in the range of cells A2 to A5.
=COUNTIF(A1:A10,100)	Count cells equal to 100.
=COUNTIF(A1:A10,'>30')	Count cells greater than 30.
=ABS(A2)	Find the absolute value of the number in cell A2.
=SQRT(A2)	Find the square root of the number in cell A2.
=EXP(A2)	Find the exponential of the number in cell A2, that is, *e* raised to the power of the value in cell A2.
=LN(A1)	Find the natural logarithm of the number in cell A1.
=LOG(A1)	Find the logarithm (to the base 10) of the number in cell A1.
=POWER(*x n*)	Returns the number *x* raised to the power of *n*

Table 10.1 Built-in functions in Excel

Graphing in Excel

Select the block of cells in Excel containing the data to be plotted (which may include headings). The *x*-axis data column should always be to the left of the *y*-axis. For example, place -axis data in column A and *y*-axis data in column B.

Click on the *Insert tab* and choose the graph type from the *Charts* area, usually scatter if the data are continuous. Graphs created on a separate Excel sheet can easily be copied and pasted into a Word document.

Graphs embedded into an Excel worksheet can be edited even after they have been inserted. Experimental data will show scatter due to random errors in the measurement. You can add a trendline by right clicking on a data point and then selecting *Add trendline*. If the data lie on an approximately straight line and a linear relationship is expected then select linear in *Trendline options*. Check the relevant boxes to display the equation of the line (regression equation) and the correlation value.

Simulations with Excel

Computer modelling is the process of creating computer-based representations of the structure and interactions of systems. It is used to understand the underlying causal factors of phenomena, to allow prediction and to bring theory and experiment together. The main issues in developing a computer model are deciding on its assumptions and simplifications, approximating but simplifying real-world conditions, and introducing its limitations.

Models can be deterministic or stochastic. **Deterministic models** are calculated with fixed probabilities – they always change in the same way from chosen values of variables (for example, exponential, logistic growth and the predator–prey models). **Stochastic models** use a random-number generator to create a model with variable outcomes (for example, the spread of infectious disease in a population). Every time you run the model you are likely to get different results, even with the same values of variables. Using the *Random function* in a spreadsheet (to simulate the rolling of dice), stochastic models of environmental phenomena can be created and explored, and data from a number of simulations can be collected and analysed.

Expert tip

Excel provides two functions for generating random numbers (remember that a function requires '=' in front of it):

RAND() – generates a random number between 0 and 1

RANDBETWEEN(*a*, *b*) – generates a random integer between and *b*

These functions are volatile, so when there is a change to the worksheet their value is recalculated and a different random number is generated.

RANDBETWEEN only generates integer values. If you want a random number that could be any decimal number between *a* and *b*, use the following formula instead:

$a + (b - a)$*RAND()

Descriptive statistics with Excel

Spreadsheet programs, such as Excel, have a number of built-in (and add-in) statistical functions. The term 'average' refers to the 'centre of distribution', which refers to the mean, the mode or the median, which measure the central tendency of a sample.

Descriptive statistics	Excel formula	Comment
Arithmetical mean or mean	=AVERAGE(range)	You should never calculate a mean from numbers that are means.
Median	=MEDIAN(range)	If there are an even number of values, this is the mean of the middle two values.
Mode	=MODE(range)	The value that occurs most frequently.

Table 10.2 Statistical functions available in Excel

Use of these Excel formulas is illustrated in Table 10.2. In many cases the quantities measured are continuous variables and will show a normal (Gaussian) distribution, and so the arithmetical mean is the most appropriate descriptive statistic to use.

If the mean of a sample is calculated then a measure of the variation, dispersion or spread of the data should also be calculated.

The range is given by the Excel formula: =MAX(range)–MIN(range), where MAX returns the largest value in a range and MIN the smallest. This is the simplest but least useful function since it is a relatively crude measure that does not take the other (intermediate) values into account.

The variance (of a population sample) is given by the Excel formula: =VAR(range), but this is not useful as a descriptive statistic since it is not in the same units as the measurements.

The standard deviation (of a population sample) is given by the Excel formula: =STDEV(range). The standard deviation (SD) is the square root of the variance and gives a good indication of the variability or 'spread' of a set of data around the mean. 68.2% of the results are within 1SD of the mean, 95.4% are within 2SD of the mean and 99.7% are within 3SD of the mean.

The standard error of the mean is given by the formula: =STDEV(range)/ SQRT(COUNT(range)). This gives an indication of the confidence of the mean. The 95% confidence interval is given by the formula: =CONFIDENCE(0.05, STDEV(range), COUNT(range)).

The value of 0.05 is used to give the 95% (0.95) confidence interval which means there is a 95% probability that the real or true mean lies within ± confidence interval (CI) from the measured mean (see Figure 10.1; see also Figure 9.3 on page 122). It indicates the percentage number of times that the calculated interval actually contains the true population mean when the process of taking *n* samples is repeated a large number of times. However, this means that there is still a 1 in 20 probability that the calculated confidence interval will not contain the true population mean. The upper and lower limits of this range are called the confidence limits and can be shown as error bars on line graphs or bar charts.

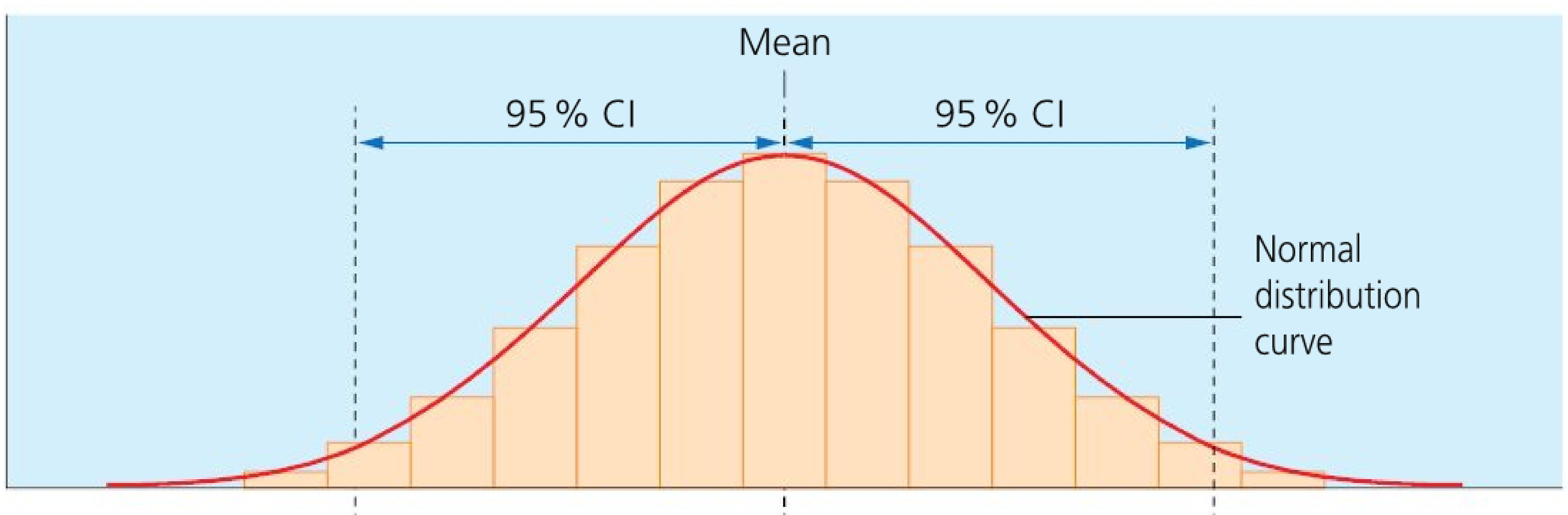


Figure 10.1 The normal distribution curve and 95% confidence intervals

Excel can also perform a *t*-test and chi-squared test:

- *t*-test: **https://www.rwu.edu/sites/default/files/downloads/fcas/mns/running_a_t-test_in_excel.pdf**
- Chi-squared: **https://support.office.com/en-us/article/chisq-test-function-2e8a7861-b14a-4985-aa93-fb88de3f260f**

Data logging

Data loggers are electronic devices that record data over time, using sensors (Figure 10.2). There are many different sensors, each measuring different abiotic variables (see Chapter 2, page 26), such as carbon dioxide concentration, relative humidity, dissolved oxygen concentration, pH, turbidity and temperature.

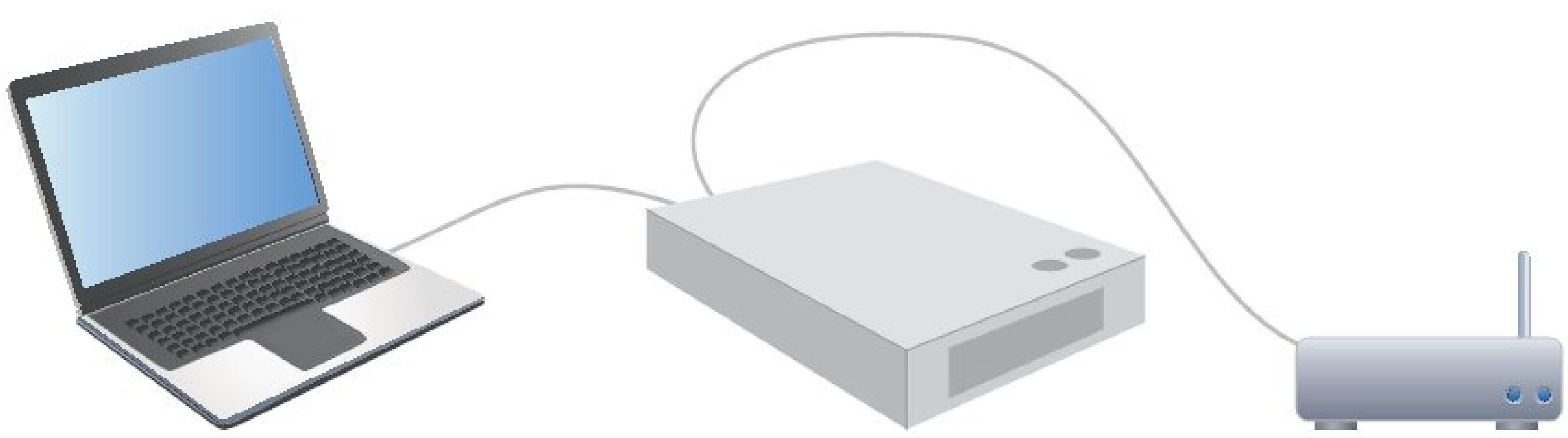


Figure 10.2 A data logger connected to a sensor and interfaced to a computer

Expert tip

Standard deviation is not the best statistic to use when comparing different sets of data, especially if the data sets are of different sizes.

Examiner guidance

If the numbers you are analysing represent an entire population, rather than a sample, then use the VARP and STDEVP functions to calculate variance and standard deviation.

Different makes of data loggers are available, but those produced by Vernier are widely used. Vernier lab manuals have basic modules which can be extended for the purposes of IAs **https://www.vernier.com/products/packages/advanced-biology/labq2/**.

Data loggers allow high-resolution data to be produced, with high levels of precision. They usually have a greater degree of sensitivity than other digital equipment, recording raw data more accurately to a greater number of decimal places. They allow data to be collected continually over the short term (that is, minutes or hours) to long term (weeks or months).

If your school has data loggers, spend some time exploring how they work, using the manuals available.

Many apps for smartphones allow you to record data (see below), if you do not have access to data loggers at your school or college.

Use of smartphones

Your smartphone is powered by a powerful computer, and contains a complete operating system which allows software programs to operate on them ('apps'). There are numerous types of app available for smartphones, many with science-specific applications. Up to 60% of them are free and many others are available at reasonable prices.

How to obtain apps

Your smartphone will already have apps installed on it. Other apps can be downloaded from online stores. Online search engines, such as Google, enable you to locate suitable apps, for example by searching for 'ESS apps for school/college'. Searching for 'Google play' brings up Android apps.

Some organizations have developed their own apps, for example:

- American Association for the Advancement of Science (AAAS): **http://sciencenetlinks.com/collections/science-apps**
- National Aeronautics and Space Administration (NASA): **www.nasa.gov/connect/apps.html#.U34C6fldV8E**

Recommended apps can be found by reading online reviews, for example:

- **https://www.sellcell.com/blog/five-data logging-apps-for-schools-and-colleges/**
- **https://www.tomsguide.com/us/pictures-story/962-best-science-apps.html**
- **www.wired.com/wiredscience/2008/07/20-iphone-apps**

Apps for ESS

New apps are being developed all the time. Here are some existing apps that you may find useful.

- **https://identify.plantnet-project.org/** Pl@ntNet is a tool to help identify plants with pictures
- **https://play.google.com/store/apps/details?id=com.cosalux.welovestars** for estimating the brightness of the night sky as part of a project on light pollution
- **www.usanpn.org/nn/mobile-apps** for data entry in the field
- **www.noisetube.net/** monitors any noise pollution anywhere, but app can be used in labs as it measures sound in decibels
- **www.inaturalist.org** allows you to record the location of a species in the field

Using smartphones to record data

Sensors are built into smartphones for specific purposes, but particular apps can use the sensors as external measuring instruments for investigations. Others record geographical data, for example, iNaturalist provides a means of recording the geolocation of a species in ecological field studies. Most smartphones have a microphone, a light sensor, and a GPS receiver.

Apps are available on smartphones that allow biological principles to be investigated, such as evolution by natural selection: **https://itunes.apple.com/us/app/evolutionary-biology/id513464425?mt=8**

Expert tip

If you use your smartphone to record data for an IA, you need to ensure that the measurements taken are accurate enough to be used in quantitative experiments. Ask your teacher if you are unsure.

Common mistake

Some apps display graphs that do not have proper axes showing independent and dependent variables, and exclude important features such as units. Some apps lack the necessary tools to assess the accuracy of their measurement.

Simulations

A computer simulation can be used to carry out IA investigations, provided it is interactive and open-ended. In order to use a simulation for an IA, you must be able to control variables and design a method that allows the control of each identified variable that affects the dependent variable.

There are many simulations available online. Some of them have PDFs that explain the simulation.

- **http://virtualbiologylab.org/** simulations mainly for ecology; two simulations on evolution (including melanistic moths) and one on cell membranes. The Simpson's index of diversity can be used to analyse data from the simulation on stream biodiversity from this website
- Other useful simulations can be found here **https://phet.colorado.edu/en/simulations/category/biology**
- A simulation of an investigation into the effect of light intensity on the rate of photosynthesis can be found here **http://www.reading.ac.uk/virtualexperiments/ves/preloader-photosynthesis-full.html**

Ideas for investigations

The peppered moth (*Biston betularia*) provides an example of natural selection in action. Although it is not possible to study the selection of the peppered and melanic varieties in the wild, there are simulations available online that allow you to do this, for example, **http://peppermoths.weebly.com/**

From the homepage select 'A bird's eye view of natural selection', which takes you to the simulator. You can select either a polluted forest (with trees covered by soot and no lichen) or unpolluted forest (with trees covered in lichen).

Figure 10.3 Screenshot from peppered moth simulation. The investigator operates a bird predator – moths visible to the operator are 'eaten' by the bird, for a fixed period of time. Relative proportions of light (peppered) moth and dark (melanic) moth are shown. This screenshot shows a polluted forest – a second background, showing unpolluted forest, is also available

If using the simulation for an IA, you need to manipulate it in some way and adapt it to a specific research question. For example, you could adjust the brightness of your computer screen to investigate how this affects the levels of predation, and selection pressure, on peppered moth populations.

You need to ensure the control of variables that might affect your dependent variables – for example, ensure background lighting in the room is constant, and allow the same amount of time for each experiment. You should replicate the investigation and calculate mean results. You could carry out a control experiment by running the simulation under full light intensity. Include screenshots from the simulation in the method and analysis, to clearly explain your methodology and results.

Coding

More than 50% percent of jobs require some degree of technological skill and this percentage looks set to increase in the coming years, particularly in the STEM (science, technology, engineering, mathematics) related field. This is a good reason to gain some experience with some basic coding skills while studying IB Diploma group 4 subjects.

Many topics in ESS lend themselves to coding-type activities, including atmospheric and climate modelling, population dynamics, ecosystem models, biodiversity analysis, food production models, soil transport and resource use. Indeed, modelling a 'theoretical curve' for comparison with experimentally derived data could help with many different IA investigations.

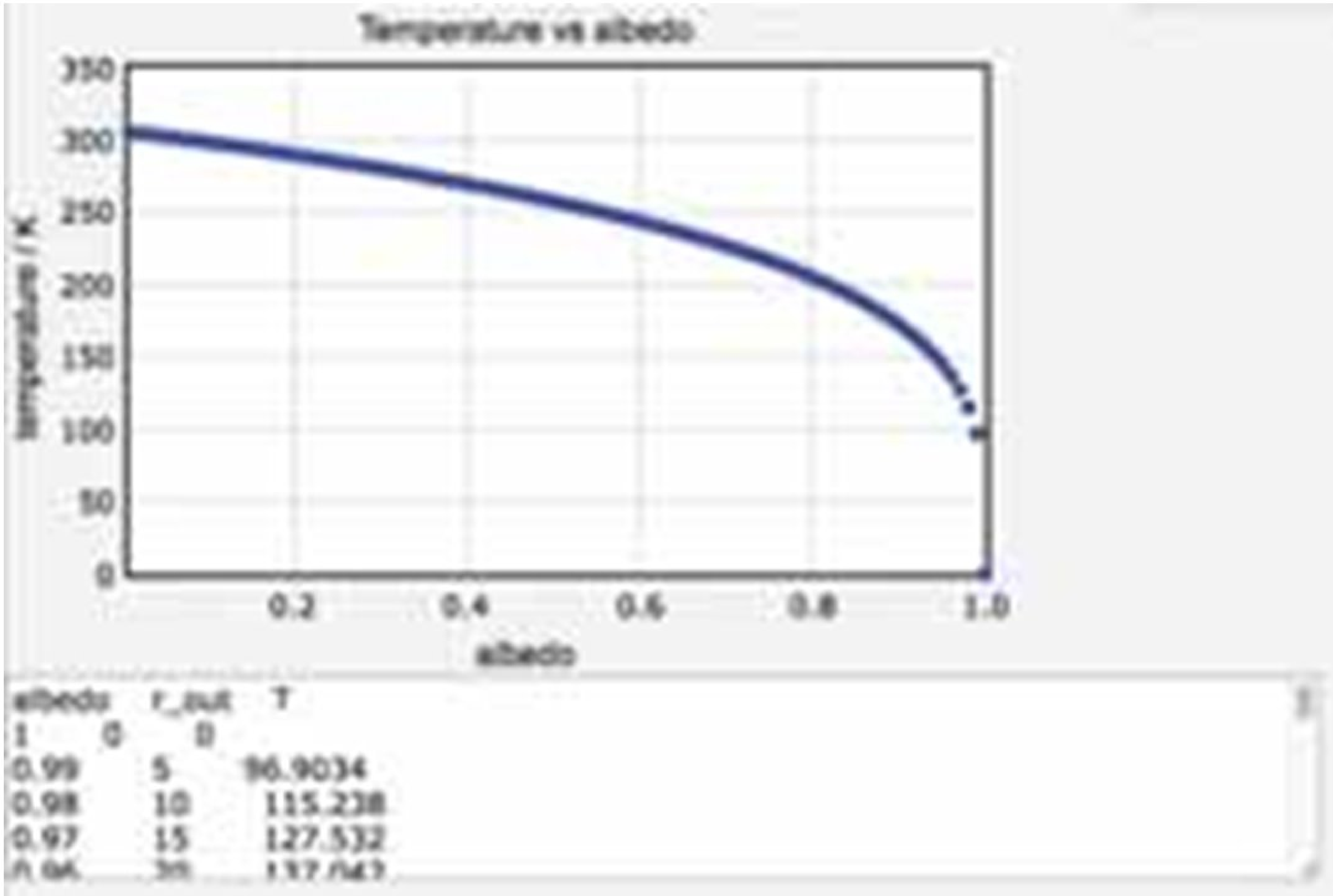
One language that lends itself to this kind of visual modelling is Python, or more specifically, VPython, which is the Python programming language plus a 3D graphics module called Visual. There are a number of online IDEs (integrated development environments) where students can code using Python and/or VPython without the requirement to download any software. These include Cloud9 (**c9.io**), GlowScript (**glowscript.org**) and Trinket (**trinket.io**).

As an indication of the power of VPython, the short block of code below was used to create a simple zero-dimensional model of the relationship between albedo and temperature of the Earth (Figure 10.4). A zero-dimensional model assumes the Earth to be point-like with the same temperature everywhere (that is, it ignores the effects of latitude, longitude and altitude) and simply models the balance between incoming and outgoing radiation at the Earth's surface. If you're interested in this, search for 'zero-dimensional climate model' online for further information on how the model can be made more realistic and to investigate how higher-dimensional models are developed. Additionally, you could do some research into the 'Daisyworld' model of Lovelock and Watson.

Source: David Fairley, **https://trinket.io/glowscript/2682d6dc56**

Figure 10.4 Coding to simulate a simple model of Earth's climate system

The output of the code is shown in Figure 10.5. Note that the data in the window at the bottom of the screen may be copied and pasted into a spreadsheet for further analysis, if so desired.



Source: David Fairley

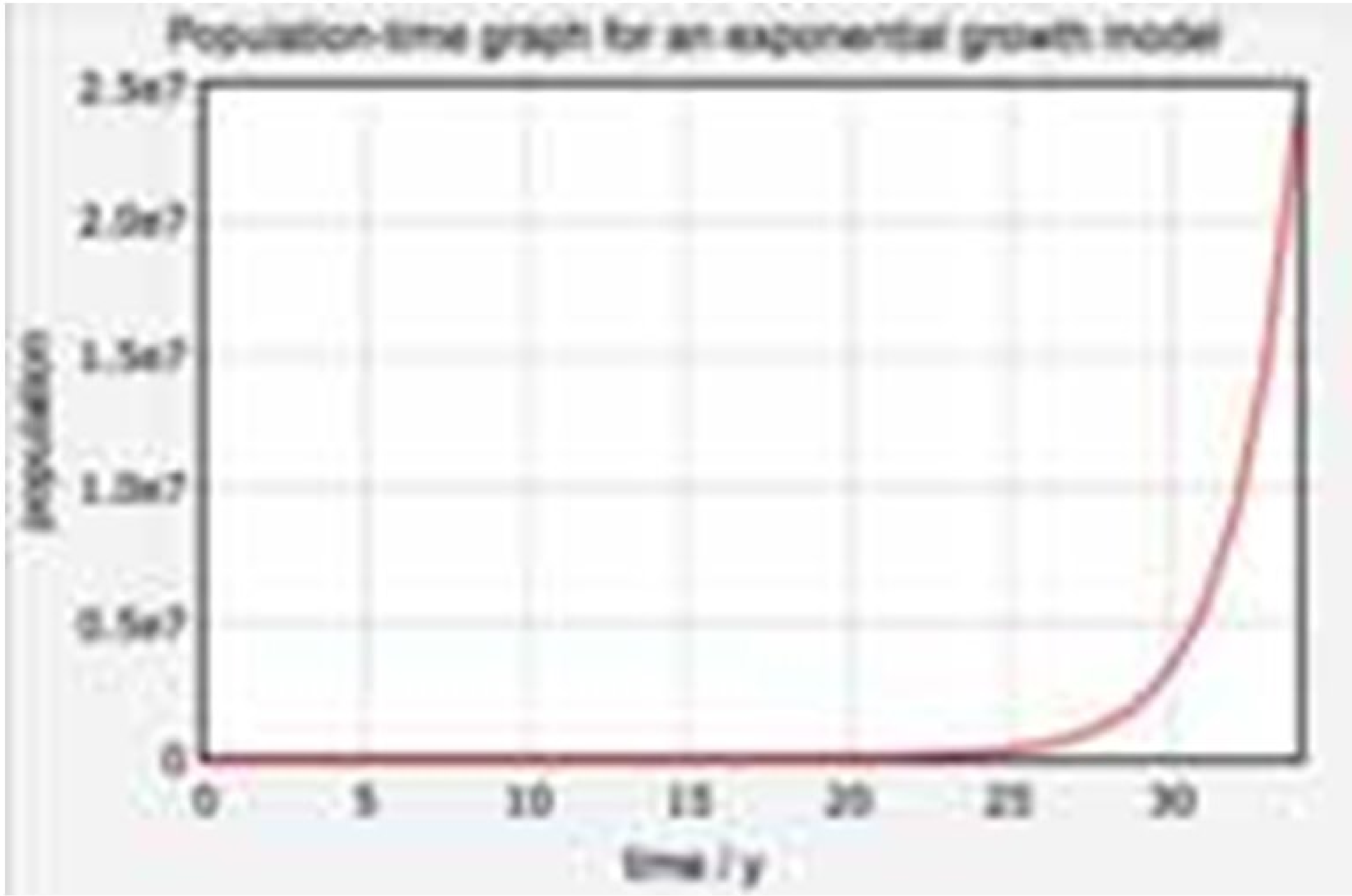
Figure 10.5 Output from the code to simulate the effect of albedo (reflectivity) on Earth temperature

The code in Figure 10.6 generates two graphs that illustrate the difference between exponential and logistic growth. In exponential growth (J-shaped curve) the growth rate remains independent of population size, so as the population gets larger it grows faster and faster, whereas in logistic growth (S-shaped curve) the growth rate diminishes as the population approaches a limiting value, called the carrying capacity, due to competition for limited space and resources.

Source: David Fairley, https://trinket.io/glowscript/5979c1d213

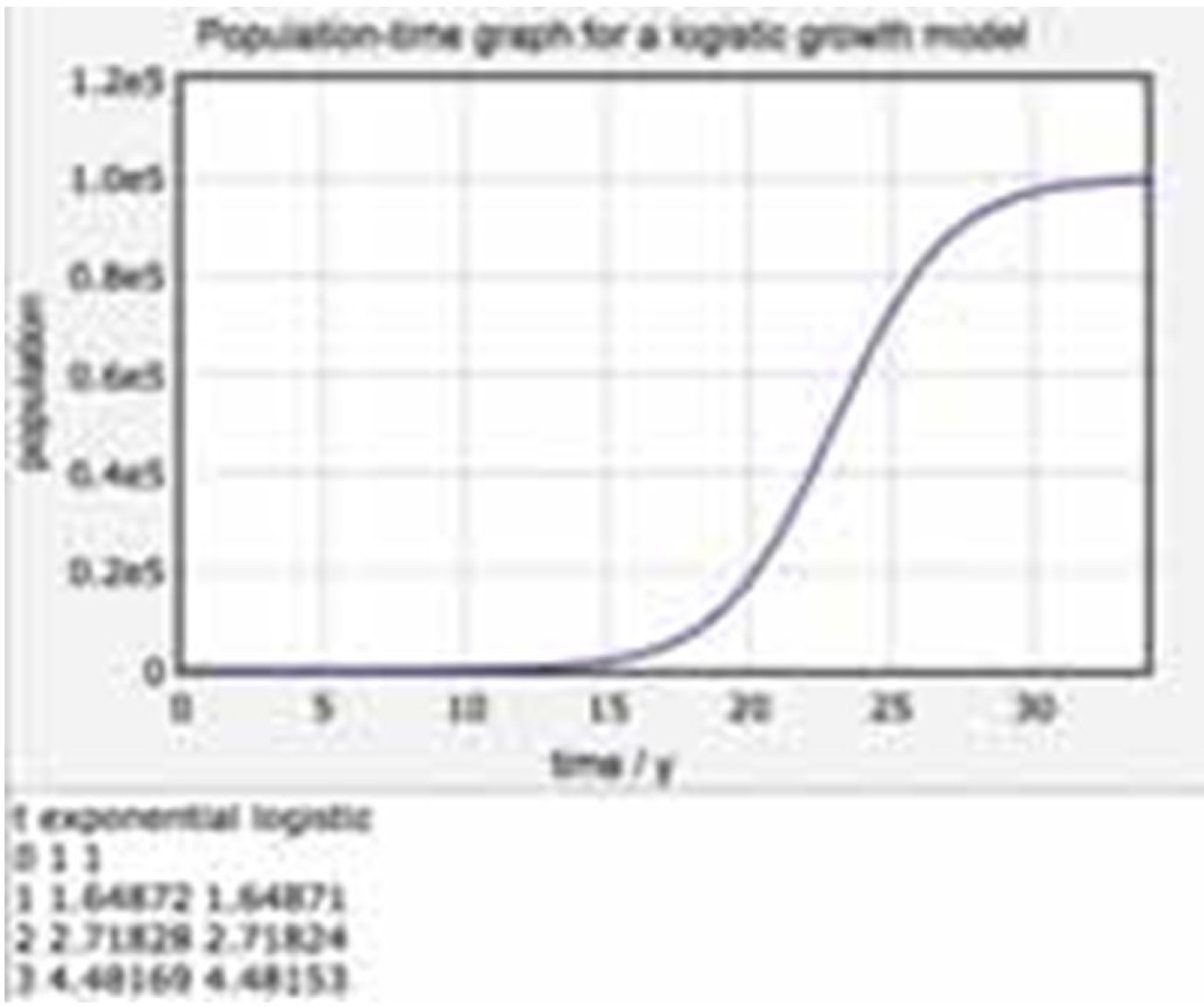
Figure 10.6 Code to illustrate the difference between exponential and logistic growth

The two graphs are shown in Figure 10.7 and Figure 10.8. Note the difference in the scales on each *y*-axis.



Source: David Fairley

Figure 10.7 Output showing exponential population growth



Source: David Fairley

Figure 10.8 Output showing logistic (S-shaped curve) population growth

Learning some basic coding skills is a very worthwhile endeavour, and there are some excellent introductory videos on how to use VPython and GlowScript on YouTube, or at **www.glowscript.org**.

11 Secondary demographic, development and environmental data

Sources of secondary data

Using the census

www.ons.gov.uk/census and **www.ukcensusonline.com**

A census is the official population count. In the UK, the census is carried out by the Office of Population Censuses and Surveys (OPCS). It has taken place every ten years since 1801 (except 1941 when the country was at war). The census not only counts the size of the population but also collects information on a range of economic and social variables such as family income, occupation and long-term illnesses.

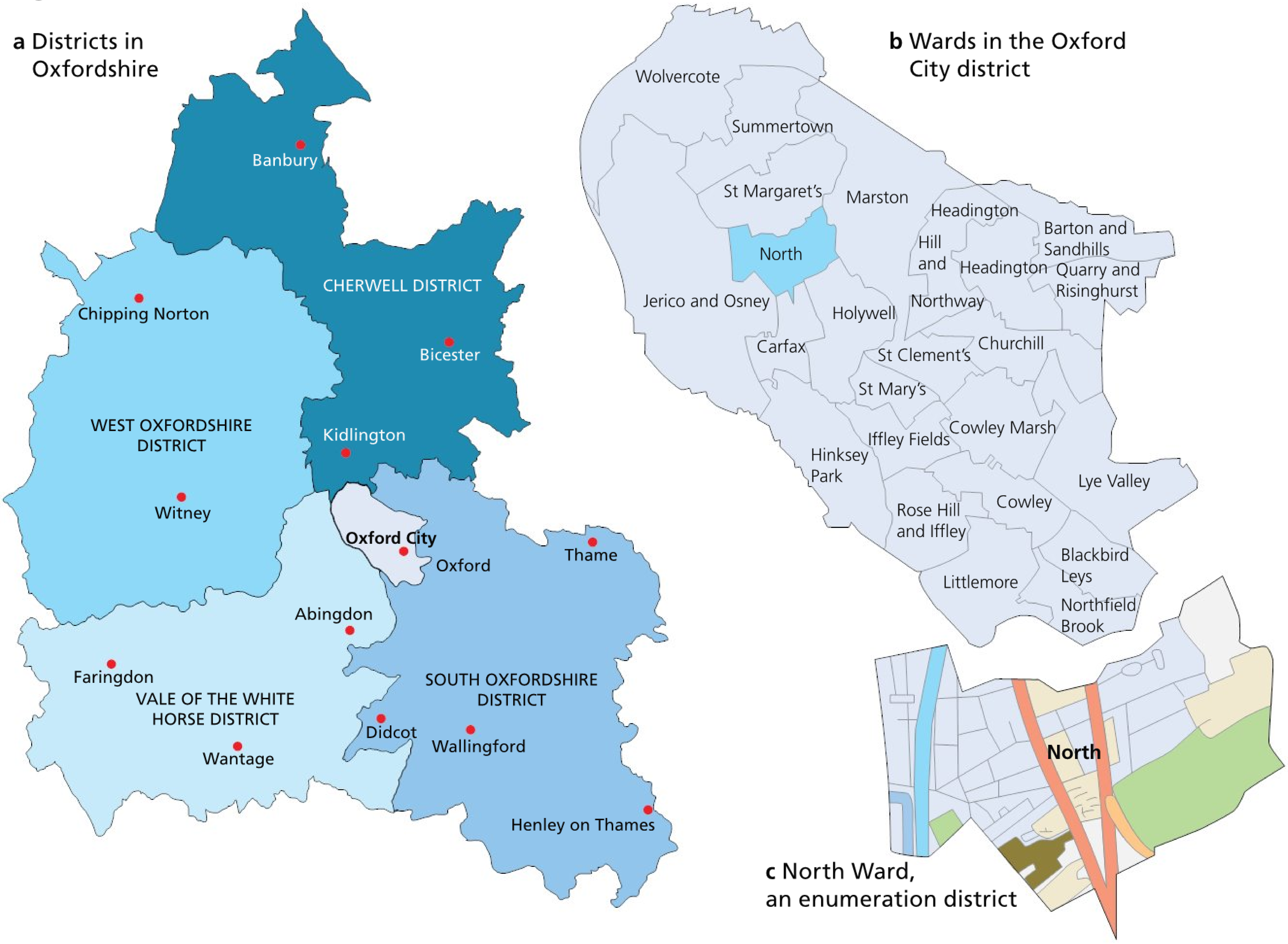
Censuses continue to be one of the most important tools for understanding human populations scientifically. Geographic information systems (GIS) now play a key role in census data dissemination and in the analysis of population and household data.

Census data can provide the foundation for a range of investigations including:

- analysing changing population characteristics in selected areas over time
- relating population profiles to environmental deprivation/affluence
- mapping the spatial distribution of particular populations.

Censuses can also show data at a local level. For example, **districts** are large areas that may contain a city or large rural area. In contrast, a **ward** is an administrative district of a town or rural area. **Enumeration districts** are the smallest areas for which census data are available. Figure 11.1 shows an example of a district, ward and enumeration district from Oxfordshire, UK.

Figure 11.1 Districts, wards and enumeration districts



UK National Statistics

www.statistics.gov.uk

UK National Statistics provide data on a wide range of themes and link to all government departments who are responsible for producing statistics. The themes most likely to be of interest include:

- **population**: population statistics describe the demographic characteristics of the UK population. These include statistics on the size and geographic distribution of the population, on the factors driving population change (births, deaths and migration) and on topics such as families and older people
- **migration**: available information covers migration into and out of the UK, migration within the UK and related matters such as immigration control, asylum (people seeking protection in a country other than where they normally live) and population by nationality and country of birth
- **agriculture and environment**: information and statistics from across the UK about the agriculture, natural environment, fishing, food and forestry sectors
- **energy**: energy statistics include prices, fuel poverty (being unable to afford to heat one's home) and energy sources, such as coal or oil
- **travel and transport**: statistics relating to all modes of travel and transport within Great Britain.

Neighbourhood Statistics

http://www.neighbourhood.statistics.gov.uk

Neighbourhood Statistics provided by the Office for National Statistics can be an excellent source of information for local inquiries. Some of the most useful features are the downloadable data sets and scale maps which show small-scale boundaries.

Other sources of population data include internet sites such as the CIA World Factbook (**https://www.cia.gov/library/publications/the-world-factbook/**) and Population Reference Bureau (**https://www.prb.org/**). PRB produces an annual population data sheet (**https://www.prb.org/2018-world-population-data-sheet-with-focus-on-changing-age-structures/**).

Geographical information systems

A **geographical information system (GIS)** is designed to capture, store, manipulate, analyse, manage and present all types of geographically referenced data. GISs are used by a wide range of academic disciplines along with an array of public and private organizations.

The earliest GIS programmes were very basic compared to their modern counterparts, simply allowing mapped information to be stored in computerized form. GISs made maps easier to store, reproduce and update. The Canadian government developed the first computerized geographical information systems in the 1960s, called the Canada Geographic Information System. It was used to store, analyse and manipulate data for the Canada Land Inventory. This was an attempt to determine the land capability of rural Canada by mapping information relating to soils, agriculture, recreation, wildlife, forestry and land use at a scale of 1 : 50 000.

As GISs developed, programmes became more sophisticated with more and more databases being linked to the base maps which are the initial building blocks of such programmes. Each theme or database, such as population density and geology, is like a layer of data in map format that is linked geographically to other data layers in similar formats. GISs can project combinations of geographical interrelationships onto a single map, or alternatively individual themes can be analysed separately. GISs allow all sorts of information to be visualized on a map so that complex relationships can become apparent in a way that cannot be matched by spreadsheets or tables of statistics. Compared to flat

Key definition

Geographical information system (GIS) – a computer system that allows different types of geographical data to be linked to a location and displayed in an easily understandable form.

paper maps, GISs can produce impressive three-dimensional images and create virtual-reality landscapes. Many GIS systems have the capability of incorporating aerial photography, satellite data and radar imagery into their data layers.

GISs are used advantageously by public and private organizations in virtually every sector of the economy. The benefits of using a GIS include:

- cost savings and increased efficiency
- improved decision-making
- better communication
- more efficient record-keeping
- many aspects of our lives are influenced by GISs without many of us even realizing it, for example:
  - Energy companies use GISs for the efficient distribution of power to households and organizations.
  - GISs are responsible for many of the maps that we use on the internet.
  - Local authorities can use GISs to identify houses in danger of flooding.

Environment Agency

www.environment-agency.gov.uk

The Environment Agency is the public body in the UK whose responsibility it is to protect and improve the environment and to promote sustainable development. The Environment Agency database includes information on:

- flood warning and hydrometric (river and sea level) data
- environmental facts and figures, including up-to-date information on climate change
- waste data including information on waste infrastructure and waste management
- HiFlow UK, providing updated flood peak data at around 1 000 river flow gauging stations throughout the UK.

Expert tip

The HiFlow UK database in particular could provide an invaluable source of information for regional hydrology studies. Grid references are supplied for each gauging station on the database, so changes can be observed along a single river and/or comparisons can be made between a number of rivers.

Worldwide Fund for Nature

Another good source of data is the Worldwide Fund for Nature's (WWF) Living Planet Report. WWF is an international NGO (non-governmental organization) working for the protection of wilderness areas and reducing the human impact on the natural environment. See **http://wwf.panda.org/knowledge_hub/all_publications/living_planet_report_2018/?gclid=EAIaIQobChMIo4-i1_-z3gIViLHtCh3-8Q7yEAAYAiAAEgIxcvD_BwE** for the 2018 Report.

WWF also provide data for ecological footprints (see **https://wwf.panda.org/knowledge_hub/teacher_resources/webfieldtrips/ecological_balance/eco_footprint/**).

Source: **https://planeta.com/living-planet-2018/**

Figure 11.2 Front cover of the WWF 2018 report

Meteorological Office data

www.metoffice.gov.uk

The Meteorological Office database is a rich source of information on statistics for weather and climate. See also **http://www.theweatherclub.org.uk** and **http://www.metlink.org**

Digimap

Digimap allows users to view and print maps of any location in Great Britain, at a series of predefined scales, using Ordnance Survey data. Data is available either as maps generated by Digimap online or to download to use with appropriate application software, such as a GIS or CAD (computer-aided design) package. You must register your details if you wish to use Digimap.

Writing the internal

Identifying the context
- Selecting an environmental issue
- Writing a research question

Planning
- Selecting variables
- Methodology
- Safety, ethical and environmental issues
- Risk assessments
- Planning data recording

Writing the IA report

Results, analysis and conclusion
- Recording and presentation of raw data
- Data processing
- Analysing data
- Presenting data: diagrams, charts or graphs
- Impact of measurement uncertainty
- Interpreting trends, patterns or relationships

assessment report

Discussion and evaluation

- Evaluation of the conclusion in the context of the environmental issue
- Strengths, weaknesses and limitations of the investigation
- Limitations of the data and sources of error
- Improvements and extensions

Applications

- Solution to the environmental issue
- Evaluation of the solution: strengths, weaknesses and limitations

Communication

- Structure and clarity
- Relevance and conciseness
- Terminology and conventions
- Referencing
- Report format
- Academic honesty

12 Identifying the context

This criterion assesses the development of the **purpose** of your study. You will be expected to show an understanding of a broader **environmental issue** and then develop from this a focused **research question**. The investigation you propose needs to be at a scale that is appropriate for the time and resources that you have available.

Points to consider when explaining the purpose of your study and how and why you developed it:

- What environmental issue are you exploring in your study?
- What is your research question?
- How does your research question relate to your environmental issue?
- Can you justify the connection between your own study and the environmental issue that was the stimulus for your investigation?
- Is your investigation achievable in the time frame available (a maximum of 10 hours, including initial planning and development)?
- Are the necessary resources for your investigation available to you?
- Do you have the necessary numerical and analytical skills to process and analyse the raw data?

Expert tip

When identifying the context, you need to explain the broader issue you have chosen and then create a focused research question that has relevance to the broader issue.

Expert tip

You need to justify the connection between your own study and the bigger environmental issue that was the stimulus for your investigation.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
1–2	The student's report: • **states** a research question, but there is a lack of focus • **outlines** an environmental issue (either local or global) that is linked to the research question • **lists** connections between the environmental issue (either local or global) and the research question but there are significant omissions.
3–4	The student's report: • **states** a relevant research question • **outlines** an environmental issue (either local or global) that provides the context to the research question • **describes** connections between the environmental issue (either local or global) and the research question, but there are omissions.
5–6	The student's report: • **states** a relevant, coherent and focused research question • **discusses** a relevant environmental issue (either local or global) that provides the context for the research question • **explains** the connections between the environmental issue (either local or global) and the research question.

Source: © IBO 2015

Table 12.1 Mark descriptors for the identifying the context criterion

Look again at Figure 1 on page viii. Are you interested in any particular concept or topic? Think about which key concepts or topic of the ESS course interest you and see which global issues are associated with these.

Research must be focused enough to allow adequate treatment within the given word limit (1 500 to 2 250 words) and time constraints (10 hours). The best reports come from a personal connection between the candidate and their research, especially if this includes some direct investigation (field, lab or survey).

This criterion allows you to provide a background to what is being studied in your investigation. Your research question needs to be set in the context

Common mistake

Avoid research questions such as *How does the loss of natural habitat in Montreal affect the diversity of insects in the grounds of St Edmund's School?* as this research question requires an investigation of a possible causal link between the school site and the wider city – something impossible to answer within the time and word limitation of an IA.

of an environmental issue. The environmental issue can be local or global. Environmental issues are covered throughout the ESS course: pollution (atmospheric, terrestrial and aquatic), habitat alteration, and the introduction of exotic or invasive species, for example. Throughout this book there are suggestions for environmental issues you can use relating to specific parts of the course.

You must reference discussions in your IA. It is easy to overlook this, especially for local examples, because much of the information may seem to be obvious. However, think carefully about where your knowledge has come from – is it something that you know instinctively yourself, or has it come from an external source? Any information that is derived externally must be referenced. What are your sources of information, and where did you acquire your knowledge from?

Take care when outlining your research question. For example, if you are investigating the effect of pollution on plant communities, you need to state what type of pollution you are investigating: soil, air or water. You also need to ensure that you establish clear links between your research question and the environmental issue – do **not** assume that the person marking your IA will do this job for you.

Common mistake

A common problem is the failure to identify an environmental issue. This is especially the case where candidates choose to use a more traditional practical. For example, it is not enough to simply investigate the effect of different light intensities on the rate of photosynthesis in pondweed (*Elodea*), because there is no environmental issue being addressed. In this case, it would be better to look at the effect of turbidity (and therefore light levels) on *Elodea* and link this to the environmental issue of deforestation and its effect on soil erosion and increases in silt-laden water.

Expert tip

The mnemonic '**A HIPPO**' provides a good starting point when thinking about a possible environmental issue for your IA. Each letter stands for a different human cause of biodiversity loss: **A**griculture, **H**abitat loss, nvasive species, **P**ollution, **P**opulation (that is, the effects of population growth) and **O**verharvesting.

Expert tip

Secondary sources can provide context regarding the significance of the issue you have chosen. Discussion of the issue, based on literature research, helps add depth to your context and helps explain the link to your research question.

The research question should be focused and indicate how your dependent variable will be measured. Discussion of the environmental issue should include how it is connected to the research question and the experiment carried out.

A weak research question would be *To what extent do distances from a road affect the growth of lichens?* because the student is going to measure the abundance, not the growth, of lichens as a function of distance from the source of pollution (a road) and this should be explicitly stated. *Does a country's population impact on the amount of carbon emissions it produces?* would also be an inadequate research question because it is not very well focused or coherent. A more sophisticated question would have examined per capita carbon production, linked this with a development index, or determined which of these is the most relevant factor in predicting carbon emissions.

A good research question would be *To what extent has logging impacted the biodiversity in tropical rainforest, as measured by Simpson's diversity index, found in two areas of the Danum Valley Conservation Area?* The research question is relevant, coherent and focused, and mentions the independent and dependent variable and how it will be measured.

Common mistake

Although the topic chosen for an IA may be a highly relevant environmental issue, candidates often give a brief account or summary of the context, not a discussion. You need to make sure that you **discuss** the environmental issue and explain the link to your research question. Without a clear environmental issue, it is difficult to achieve good marks (that is, a 5 or 6) for the identifying the context criterion and any marks at all for the discussion and evaluation criterion.

As well as describing and explaining a research question, this criterion should include background information that provides context and reasons behind the investigation. Background information needs to be focused and contain relevant information; superficial or irrelevant material should be avoided. The background will provide a brief overview of the environmental issue and current knowledge, with a special emphasis on the environmental literature specific to the individual investigation topic. It also serves to support the argument behind your report, using evidence from that research area.

Expert tip

A good way of establishing whether your proposal is at the correct level for IB, is to consider whether a student of a much younger age than yourself could carry out the research. If the answer is 'yes', the research question is probably not complex enough and you need to think again.

Identifying the context criterion checklist

Descriptor	Complete
You have discussed a relevant environmental issue (either local or global) that provides the context for the research question.	
You have developed a clear and sharply focused research question.	
The research question refers to independent and dependent variables.	
You have explained the connections between the environmental issue (either local or global) and the research question.	
You have given a prediction of what you expect to happen and why.	
You have given background to the environmental issue and local context and quoted references.	

13 Planning

This criterion assesses the extent to which you have developed appropriate methods to gather data that is relevant to the research question. The emphasis in this criterion is therefore on the **development of the methodology** of the investigation. There must also be an assessment of safety, environmental and ethical considerations, where applicable.

Expert tip

Data can be primary or secondary, qualitative or quantitative, and may utilize techniques associated with both experimental or social science methods of inquiry.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
1–2	The student's report: • **designs** a method that is inappropriate because it will not allow for the collection of relevant data • **outlines** the choice of sampling strategy but with some errors and omissions • **lists** some risks and ethical considerations where applicable.
3–4	The student's report: • **designs** a repeatable* method appropriate to the research question but the method does not allow for the collection of sufficient relevant data • **describes** the choice of sampling strategy • **outlines** the risk assessment and ethical considerations where applicable.
5–6	The student's report: • **designs** a repeatable* method appropriate to the research question that allows for the collection of sufficient relevant data • **justifies** the choice of sampling strategy used • **describes** the risk assessment and ethical considerations where applicable.

Table 13.1 Mark descriptors for the planning criterion. *Repeatable, in this context, means that sufficient detail is provided for the reader to be able to replicate the data collection for another environment or society. It does not necessarily mean repeatable in the sense of replicating it under laboratory conditions to obtain a number of runs or repeats in which all the control variables are exactly the same

Expert tip

Investigations in ESS can be scientific or social-science based. The planning criterion allows for the assessment of a broad range of investigations. In this criterion you must justify the choice of, for example, the sampling strategy and statistical analysis, which would vary according to the type of study undertaken:

- the method used for sampling recipients in a questionnaire (social-science based study)
- selection of the number of repeats and the control of variables in a laboratory experiment (scientific study).

Some points to consider:

- Is the methodology appropriate to the focused research question?
- Have you clearly explained why the methodology was selected?
- Have you justified your sampling methodology?
- Are there sufficient raw data processed and analysed to lead to a valid conclusion?
- Have you considered ethical or safety considerations? Have you, if relevant, paid attention to the IB animal experimentation policy (which includes guidelines on working with human subjects)?
- Have you written about your strategies for upholding safety and/or ethical standards in the report?

It is essential that you have a good justification of the sampling method – you will lose marks if you only describe it. You need to establish why the method was chosen over another one, and why your data was taken in the places selected rather than elsewhere. Why was this method, and no other, used? For example, if you are using quadrats to sample plant communities, why did you used one size of quadrat (for example, 1 m) rather than another (for example, 2 m)?

Expert tip

Once you have decided on your method, consider whether it will result in sufficient data. You must revisit your method before embarking on any data collection or analysis.

You need to clearly show your knowledge of how to recognize bias and minimize it by explaining how and why your selected research areas and methodology were chosen. This is the central focus of this criterion: do this and you will score a good mark in this section of the IA.

Your risk assessment, environmental assessment and ethical considerations also need to have sufficient detail to justify why and how they were done. It is not sufficient to simply say 'all relevant safety measures were followed', for example. Hazards need to be identified, details of specific measures and why they were followed, and how risks were averted, need to be explained.

Expert tip

An investigation that relies on secondary data does not necessarily need an assessment of risks or ethical concerns, although you still need to state that this is the case and why you have decided not to include this aspect. However, when using secondary data, there is always the ethical concern of ensuring that you are not engaged in purposeful bias, which could be mentioned.

Expert tip

When carrying out surveys, ethical considerations include the need to guarantee the anonymity of subjects. A safety issue would be the need to be accompanied by a friend when approaching members of the public in order to fill out a questionnaire.

The independent variable and its range need to be stated and justified, and the dependent variable identified. Preliminary trials may be used to determine the most appropriate values for an independent variable. Introduction of the dependent variable should lead to a description of how measurements will be taken. The discussion of controlled variables is needed to demonstrate that you understand and appreciate that other factors may impact on values of the dependent variable. Scientific names need to be used here and throughout the report.

The variables could be classified and tabulated with an emphasis on explicitly identifying the controlled or monitored variables that affect the results. Table 13.2 shows one suggested format for the presentation of information about variables. The example is an ecological investigation determining the effect of forest type (containing native or non-native trees) on leaf-litter invertebrate diversity.

Type of variable	Variable	Method for control	Reason for control
Independent	Forest type (native versus non-native)	Forests will be sampled at the same altitude and the same time of year.	N/A
Dependent	Leaf-litter invertebrate diversity	Invertebrates will be sampled using quadrats of a standard size, and collected during a specific period of time (for example, 10 minutes per quadrat).	N/A
Monitored	Temperature	Values of temperature will be recorded at ground level at the same time of day for each sample.	Temperature can affect the activity and abundance of organisms. Metabolic activity is affected by temperature.
Monitored	Humidity	Values of humidity will be recorded at ground level at the same time of day for each sample.	Leaf-litter invertebrates are affected by humidity, for example, woodlice prefer damp/humid environments.

Table 13.2 A possible format outlining the classification of variables

The method should not be a long list of detailed instructions, but it should explain why certain actions are performed and explain the roles of certain steps. It can be written in continuous prose (as in a scientific paper) or as a list (using numbers or bullet points). Any steps or procedures designed to minimize the systematic and random errors in all of your measurements should be clearly described. The method should include the equipment used and a description of how the investigation was carried out. It needs to be written clearly – this will be reflected by your mark in both the planning and communication criteria.

Examiner guidance

Your method should be more than just a list of instructions; it should tell your teacher (and the person moderating your coursework) why you chose certain techniques or apparatus, or chose a particular statistical approach to analyse the data. Any special precautions you took to increase the accuracy, precision or reliability of your raw data should be included.

Expert tip

You should provide enough detail so that another student could repeat your work and obtain raw data without you being there.

The report needs to describe and explain the safety, ethics and environmental impact of the investigation (see pages 23–24). As well as identifying potential areas where safety is an issue in your investigation, you also need to explain how the issue will be avoided. If your investigation did not have ethical or environmental impacts then you need to state this and explain why (for example, when conducting a simulation there are no safety or ethical aspects to comment on).

Examiner guidance

You should be aware of the falsification approach to the scientific method, which assumes that a scientific hypothesis must be testable and could potentially be shown to be false by experimental data. Ideally, your data will either support (not prove) your hypothesis or falsify (disprove) your hypothesis. You should be aware of the tentative nature of scientific knowledge.

Investigating relationships

If carrying out a statistically-based investigation, there are three possible relationships (see also Chapter 9).

- Is there a **correlation** between, for example, variable X (abiotic) and variable Y (biotic)?
- Is there a **difference** in mean/median measurement between, for example, habitat A and habitat B?
- Is there an **association** between categories A and B?

When selecting other variables to control or monitor, this is a good opportunity to use your scientific knowledge to state what other variables may affect your dependent variable. What impact might they have on your dependent variable?

Minimizing errors

When designing an experiment take note of the following points:

- Ensure that the independent variable is the only major variable that is changed (manipulated).
- Include controls and comparisons to show it is only the independent variable which causes the measured biological or biochemical effect (if there is one).
- Where appropriate, select experimental subjects randomly to cancel out variation arising from biased selection (this is important in ecological investigations).
- Keep the number of replicates as high as possible, given the time constraints of the individual investigation.
- Ensure the same number of replicates is done for each value of the independent variable.
- Identify other factors which could affect the dependent variable and keep them constant (controlled variables: for example, temperature, pH, concentrations of solutions, light intensity, time for reaction, dissolved oxygen concentration, humidity, etc.). Variables that cannot be controlled, such as those in ecological investigations (pages 25–43), need to be monitored.

Data tables

The following guidelines should be followed when presenting data in tables (see also Chapter 14):

- All raw data should be presented in a single table with ruled lines and a border.
- Ideally, each table of biological results should show one relationship between the independent and dependent variables.
- Put the data for the independent variable in the first column; put the data for the dependent variable in columns to the right.
- Put processed data (for example, means, rates, reciprocals, logarithms and standard deviations, etc.) in columns to the far right.
- No calculations should be present in the table, only calculated values.
- Each column should be headed with a physical quantity, correct units and absolute uncertainty; the units should be separated from physical quantity using a solidus (forward slash) and negative exponent notation used (for example, per metre squared should be given as m^{-2}).
- No units should be in the body of the table, only in the column headings.
- Raw data should be recorded to a number of decimal places appropriate to the precision (sensitivity) of the apparatus or instrument.
- All raw data of the same type should be recorded to the same number of decimal places.

Risk assessment

Your IA report must contain a risk assessment where relevant (for example, this is not required for a simulation experiment). The three main parts of a risk assessment are:

- Hazard identification: identifying safety and health hazards associated with laboratory work.
- Risk evaluation: assessing the risks involved.
- Risk control: using risk control measures to eliminate the hazards or reduce the risks.

Detailed information about how to carry out risk assessments can be found in Chapter 1 pages 23–24.

Environmental and ethical assessment

You need to consider the impact of your investigation on any organisms you are studying and the environment they live in, if relevant to your study. Bear in mind the IB ethical policy (page 24).

Planning criterion checklist

Defining the problem and selecting variables

Descriptor	Complete
Research question	
You state and describe the correct independent variable, including range of values and units.	
You state and describe the correct dependent variable, including units and an outline of how it is measured.	
You predict, when appropriate, a quantitative relationship between the independent variable and the dependent variable(s) or expected correlation.	
You state and describe the relevant controlled variables, including units, together with why and how they are controlled or monitored.	

Methodology

Descriptor	Complete
You include a list and description of apparatus.	
You justify the choice of sampling strategy.	
You give a clear, detailed and logical sequence of reproducible steps. The method is complete and could be replicated.	
You describe the rationale or justification of relevant steps in the method.	
You include labelled diagrams and photos to help explain the methodology.	
Correct names and terminology are used.	
You describe how and why controlled variables are to be held constant or otherwise monitored (if they cannot be controlled).	
You describe how the independent variable is varied and the values/range chosen.	
You describe how the dependent variable is measured and how the processed variable(s) is/are calculated from the raw data.	
You have explored alternative methods and outlined why they are less suitable.	
Safety, ethical and environmental issues	
The plan shows awareness of safety, ethical or environmental issues related to the methodology, for example, risk assessment and ethical issues relating to use of biological organisms, and how impacts on the environment will be avoided or minimized.	

Planning and recording of data

Descriptor	Complete
You plan to collect a sufficient number of reliable and relevant raw data points over a wide data range.	
You plan to collect a suitable number of repeated and averaged readings.	
You plan to collect relevant qualitative data (observations).	
You ensure that your data collection is relevant to the initial research question.	
You plan to collect sufficient data for any statistical analysis (if appropriate).	
You plan to collect raw data that records units, as well as being recorded to an appropriate precision.	
You plan to record physical conditions, such as climate (for example, temperature, wind speed), if these affect the value of your dependent variable(s).	

14 Results, analysis and conclusion

This criterion assesses the extent to which you have collected and appropriately analysed your data. Any analysis and conclusions based on insufficient data will be superficial and will be unable to adequately address your research question.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
1–2	The student's report: • **constructs** some diagrams, charts or graphs of quantitative and/or qualitative data, but there are significant errors or omissions • **analyses** some of the data but there are significant errors and/or omissions • **states** a conclusion that is not supported by the data.
3–4	The student's report: • **constructs** diagrams, charts or graphs of quantitative and/or qualitative data which are appropriate but there are some omissions • **analyses** the data correctly but the analysis is incomplete • **interprets** some trends, patterns or relationships in the data so that a conclusion with some validity is deduced.
5–6	The student's report: • **constructs** diagrams, charts or graphs of all relevant quantitative and/or qualitative data appropriately • **analyses** the data correctly and completely so that all relevant patterns are displayed • **interprets** trends, patterns or relationships in the data, so that a valid conclusion to the research question is deduced.

Table 14.1 Mark descriptors for the results, analysis and conclusion criterion

Analysis

In the planning section, you will have considered whether your plan will generate sufficient data for a detailed analysis.

It is essential that the analysis is coherent with the research question. To show variation in data, standard deviations can be calculated that show the spread of data around mean values – if this is done, they should be included in corresponding graphs as error bars.

Check carefully that any calculations have been done properly – you will lose marks if there are mistakes.

Make sure that units are present in tables, that there are an appropriate number of decimal places in calculations and data tables (appropriate for the level of precision used), and that graph axes are fully labelled with units. Failure to do so will lead to loss of marks in the communication criterion for not following conventions.

Recording and presentation of raw data

The presentation of raw data needs to be accurate and relevant qualitative observations included. Raw data must then be processed in some way: at its most basic, this will take the form of calculating means and standard deviations. You can use programs, such as Microsoft Excel, to analyse data (see pages 137–139).

Raw data: these are the data collected without any processing. They are just the values of each variable collected. They are often difficult to use for data analysis, and usually need to be processed in some way. Observations are another example of raw data (page xi).

Processed data: data that are ready for analysis. Processing can include merging or transforming data (see Introduction, page xi).

Common mistake

A well-constructed graph of raw data may be considered under the first aspect of the RAC criterion, but will not be sufficient on its own to score full marks, as it is not considered to be analysis. Processed data should be shown in the graph to achieve full marks, and data upon which the graph is constructed should be present in the report.

Expert tip

If, once results have been gathered, there is a lack of primary data, it is possible to use secondary data from data banks or simulations to provide sufficient material for analysis.

Numerical raw data must be presented in tables with appropriate headings and units. The decimal places used for each variable must be consistent with the precision of the equipment used (for example, if a balance can measure to two decimal places, this is the precision that should be used to record the raw data). The same number of decimal places must be used consistently across all data for each variable.

When large amounts of data have been collected using, for example, data logging, you should only present a representative sample of the raw data.

You need to ensure that your sample size is large enough for data processing:

- >30 is considered a large sample.
- 15–30 is a small sample.
- 5–15 is a very small sample.
- <5 is usually considered too small a sample to calculate standard deviation or apply tests such as the -test.

Expert tip

If you used Excel to produce a statistic such as a *p* value or a correlation coefficient, you need to know what the value actually represents, and include this interpretation in your report.

Common mistake

Standard deviation is often applied to a sample size that is too small (sample size, *n*, <5).

Expert tip

Qualitative observations for a fieldwork investigation should include a site description: this could be in the form of maps, sketches or photographs with annotations (see Chapter 1, pages 17–19).

Expert tip

Raw data from data logging may be shown as a graphical readout, and accompanied by necessary information in the axes titles, such as units. A representative graphical readout revealing how data are derived is acceptable. In this way the derived data becomes the raw data.

Data processing

If carrying out a statistical test (Chapter 9, pages 120–136), your investigation should have both a hypothesis and null hypothesis. For example, if carrying out a test to see if there is an association between two variables x and y

- **Hypothesis**: there *is* a statistically significant association between variables x and y.
- **Null hypothesis**: there is *no* difference (or association) between variables x and y

Examiner guidance

You are not expected to show full calculations; examples will be sufficient. A worked example from a calculation carried out on a spreadsheet or a programmable calculator is not expected.

The concluding statement of your investigation report should cover the following points:

1. What is the result? State the outcome of your statistical test and whether it is larger, equal to or smaller than the critical value at your specific degrees of freedom at 5% significance level.
2. What does this mean? Do you accept or reject the null hypothesis?
3. How confident are you? What is the probability that the result has happened by chance? (This is set at 5% in ecological studies, which means you can be 95% certain that your results show a real association between the two variables.)
4. Explain the reasons for your results, using material you have introduced in the first part of your report (identifying the context).

Presenting data: graphing

One of the most effective ways to communicate the results of an investigation is to create an effective visual representation (a graph) of the data that have been counted, measured and calculated. Often you can easily see patterns in a graph that may not be as obvious in a data table. Graphs show trends in data clearly and can be used to summarize complex relationships between independent and dependent variables.

Figure 14.1 can be used to select the correct graph for your data:

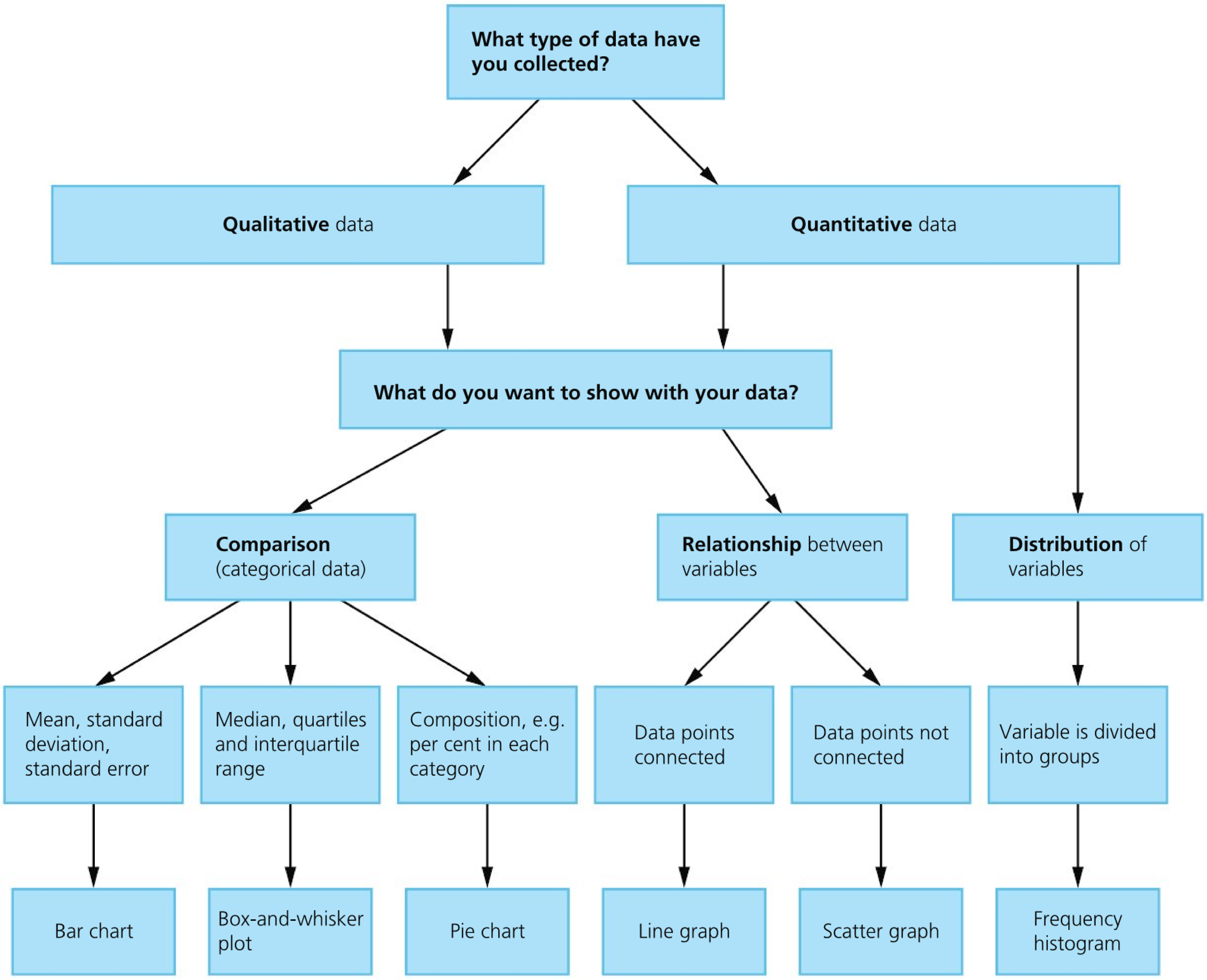


Figure 14.1 Flow chart for selecting the appropriate graph

Common mistake

Students sometimes confuse the use of bar charts, histograms and line graphs. The following should help you to distinguish between them:

Bar charts: The independent variable is a category, for example, forest type (pristine, logged and plantation), with the number of individuals in each category recorded on the *y*-axis.

- Data are in categories on the *x*-axis.
- Categories are in any order.
- Bars do not touch.

Histograms: The independent variable is not grouped into a category but into a range of numbers, for example, number of individuals at different ages in a population, where the *x*-axis divides the population into groups of different age ranges, such as 10–19, 20–29, 30–39, etc., and frequency (number of individuals) in each group is recorded on the *y*-axis.

- Data are in ranges on the *x*-axis.
- Ranges are placed in numerical order.
- Bars can touch.

Line graphs: These show a trend in data.

- Both variables show numerical data.
- Data on *x*-axis (independent variable) are numbered.
- *x*-axis data are specific data points, not ranges.
- Points are placed in numerical order.
- A line can be drawn through the points, or a line or curve of best fit added. The line should not go beyond the first or last points.

Expert tip

It is suggested that you assess data for a graph while the investigation is in progress. Any data not conforming to the trend can be identified and re-assessed.

Common mistake

Graphs are sometimes reduced in size to ensure the report is the correct page length. Graphs should not be reduced to such a size that they become uninformative, simply to stay within the page limit.

Expert tip

Different types of graphs, charts and diagrams include: bar chart, pie chart, frequency histogram, timeline, line graph, rose diagram, scatter graph, kite diagram, pie chart, Venn diagram, box-and-whisker plot, Gantt chart, frequency polygons and mindmap.

Logarithmic scales

Sometimes during an IB ESS investigation, the data collected are not easy to plot on a graph because of the very wide range of numbers involved. An example arises when measuring the number of species on an island and comparing these values to island area. Rather than plotting the averaged raw data, it is preferable to calculate the base ten logarithm of the measurements (Figure 14.2).

This can be done with a calculator or Excel: the formula is =LOG10(cell reference). The logarithm of the number only increases relatively slowly and a straight-line plot is generated. Alternatively, log-linear graph paper (Figure 14.3) can be used.

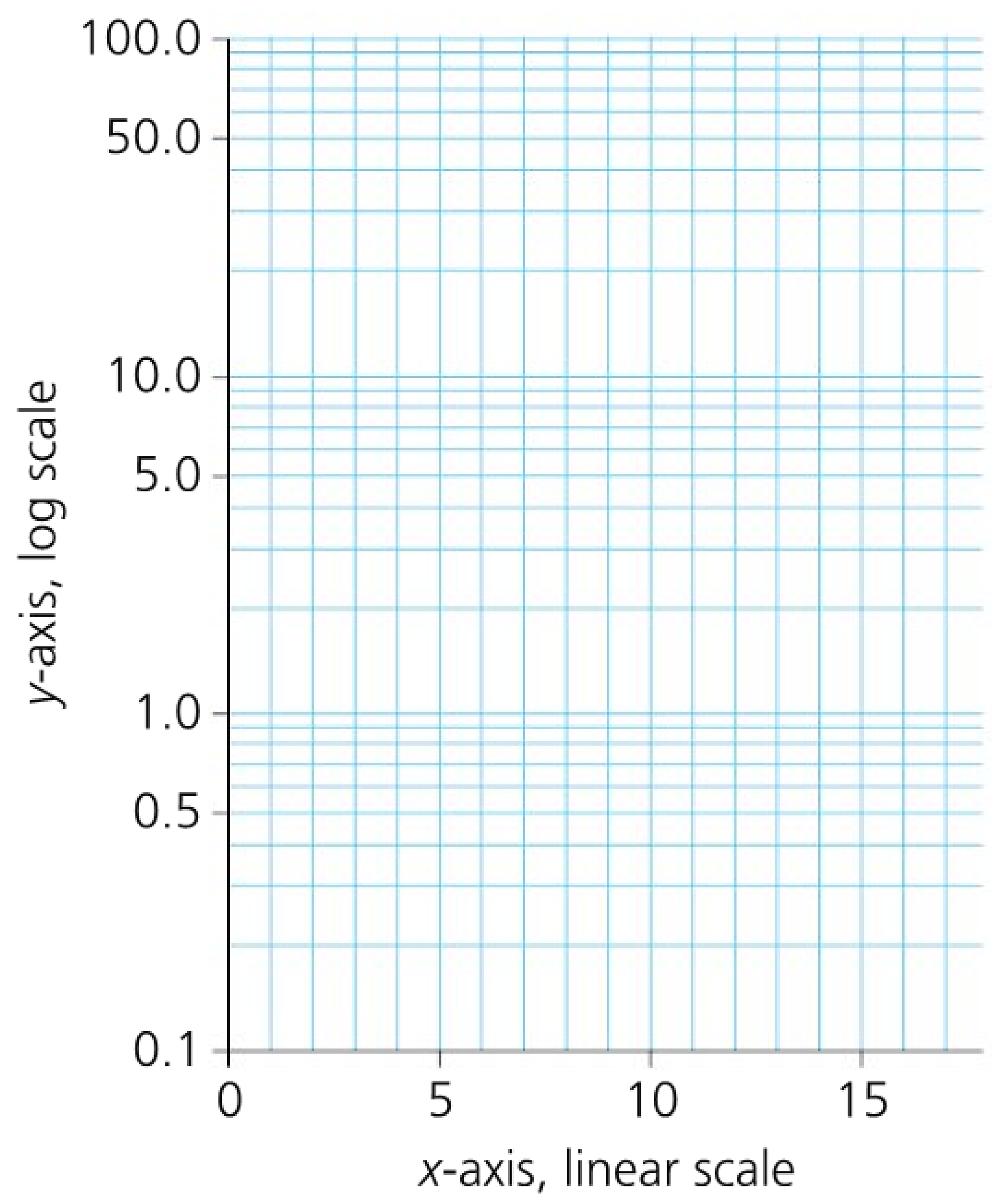


Figure 14.3 A logarithmic scale on the y-axis with three cycles: 0.1 to 1.0, 1.0 to 10.0 and 10.0 to 100. The *x*-axis has a linear scale. Numbers can be plotted directly onto graph paper without calculating their $\log_{10}$ values

Examiner guidance

- Graphing, even that of raw data, is part of processing especially if it is used to derive values (for example, gradients for rates) or equations for lines of best fit.
- Graphing of raw data when the graphing of processed data would be more appropriate is not incorrect but can be considered insufficient.
- Dot-to-dot plotting of data is acceptable for continuous data. Going further and placing a trend line on the data, especially if it is accompanied by error bars, is advisable. Calculating a correlation coefficient (*r*) can be a useful step in processing and interpretation (for example, comparison with an accepted model).
- You need to obtain sufficient data so you can be confident when drawing a trend line on your graph. A trend line may be used to show how the limited data collected fits a given model (for example, temperature optimum for seedling germination).
- Standard deviation or standard error can be useful assuming there are a sufficient number of replicates for calculation. Alternatively, range bars are acceptable for maximum–minimum values.
- The types of graphs produced should be appropriate for the data being analysed.

ACTIVITY

1. Find out about the following types of graph or other ways of representing data: histograms and bar charts, pie charts, box-and-whisker plots, triangular graphs, rose diagrams, kite diagrams and the ACFOR scale. Summarize how they are used and give examples for each.

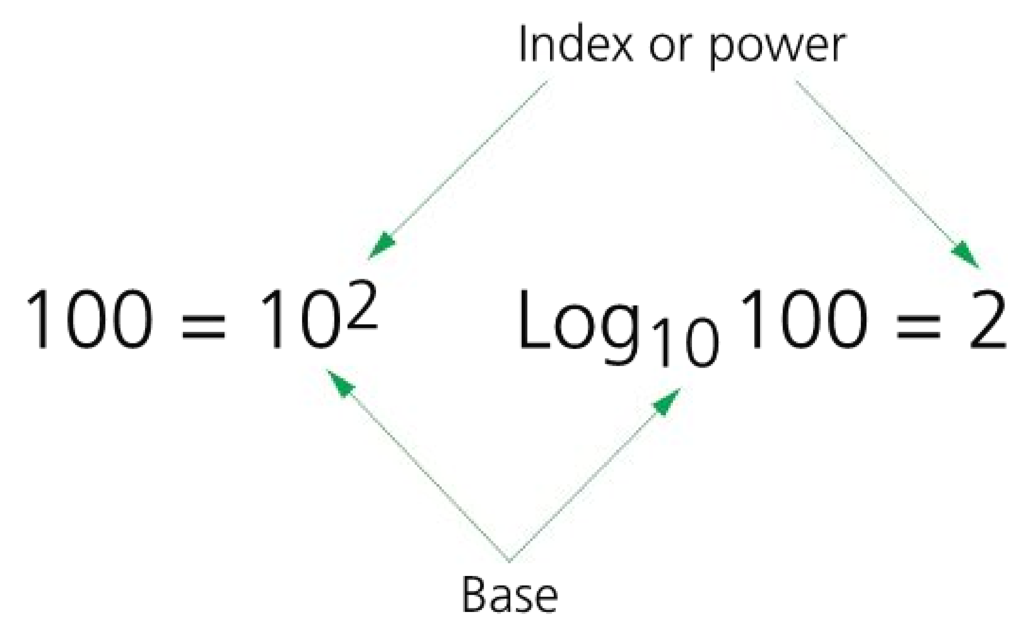


Figure 14.2 Relationship of numbers with their logarithms

Expert tip

Histograms and pie charts are for plotting the distribution of a **single** variable. There is no independent or dependent variable. If the single variable is continuous then there are no gaps between bars, and if it is discontinuous or categoric then there are gaps.

Scatter graphs are for two numeric variables when you don't yet know if there is a connection between them. Again, there is no independent or dependent variable. The variables can be plotted either way round on the *x*- and *y*-axes.

Line graphs are for two numeric variables when you know that there is a connection between them and a controlled experiment has been carried out with an independent and dependent variable. There is always a line: either joining the dots or a smooth line of best fit.

Bar charts are for two variables: a numeric dependent and categoric independent.

Variation in data

The biggest issue relating to uncertainties is the variation in the biological material: this variation can be expressed as standard deviations (SD), standard error (SE), or the maximum–minimum range. In addition, measurement uncertainty can be calculated for apparatus used in the investigation (see below). Error bars showing variation should be used on graphs and their significance explained. You can show the variation in data on graphs by plotting SD, SE or minimum and maximum values above and below mean values.

Expert tip

The most common way of showing uncertainty is by giving a measured value plus or minus (±) uncertainty. For example, a measurement of 4.01g ± 0.01g means that the experimenter is confident that the actual value for the physical quantity being measured lies between 4.00 g and 4.02 g.

Impact of measurement uncertainty

You are expected to appreciate the limitations of your instruments, and to present and discuss measurement uncertainties. The aim of a scientific investigation is to test a hypothesis and to record, as well as possible, the true value of a dependent variable (that is, to make the experiment accurate). The experimental procedure and apparatus will, however, result in measurements that vary from true values. These are known as **uncertainties**. There are several different types of uncertainty:

Reading uncertainty: For analogue instruments (for example, a metre rule or an alcohol thermometer), the scale can only be read to within a certain fraction of the smallest scale division. This is usually taken to be half the smallest division. For digital instruments (for example, a pH meter and probe, or electronic balance), it is normally taken to be ±1 of the smallest change in reading.

Calibration uncertainty: This is a calibration provided by an instrument maker against approved standards, for example, for a metre rule it might be stated that the length of 1 metre is accurate to ±0.5 mm. With increasing age and use, and extremes of low and high temperature, this calibration may not be maintained.

Random uncertainty: If a particular procedure is repeated many times, the result might not be the same on every occasion, causing readings to vary in an unpredictable way from one measurement to the next. This could be because the equipment is set up slightly differently, conditions are slightly different, or data are read slightly differently (for example, see parallax error, Chapter 1 page 15). These random differences will lead to a range of results which, assuming a normal distribution, can be statistically analysed to give a best estimate and an uncertainty for the measurement. The effect of random errors can be reduced by carrying out repeats and averaging precise results.

Systematic effects: These cause readings to vary from the true value by the same amount every time a measurement is made. Repeats *will not* compensate for systematic errors. Different apparatus or a different technique should be used and the results compared. Calibration or re-calibration of apparatus might solve systematic errors. These uncertainties differ from other uncertainties because they affect the results in the same direction. For example, if you assume a ruler's scale zero is at the end of the ruler, when it is in fact 1 mm from the end, then all the measurements made will be systematically 1 mm too small.

Zero errors: If a measuring system gives a false reading when the true value of a measured quantity is zero – that is, if equipment is not calibrated properly – this will cause a systematic error. For example, when using a balance, if the instrument is not set to zero then the apparatus will give false readings.

Expert tip

Uncertainties may also be referred to as 'errors', for example, 'random error'. Error is the difference between the true value and the measured value, and uncertainty describes the range of values within which the true value is asserted to lie.

Common mistake

Error does not refer to mistake; error refers to the value of the uncertainty.

Examiner guidance

You must recognize that all measured values have uncertainty and are not exact.

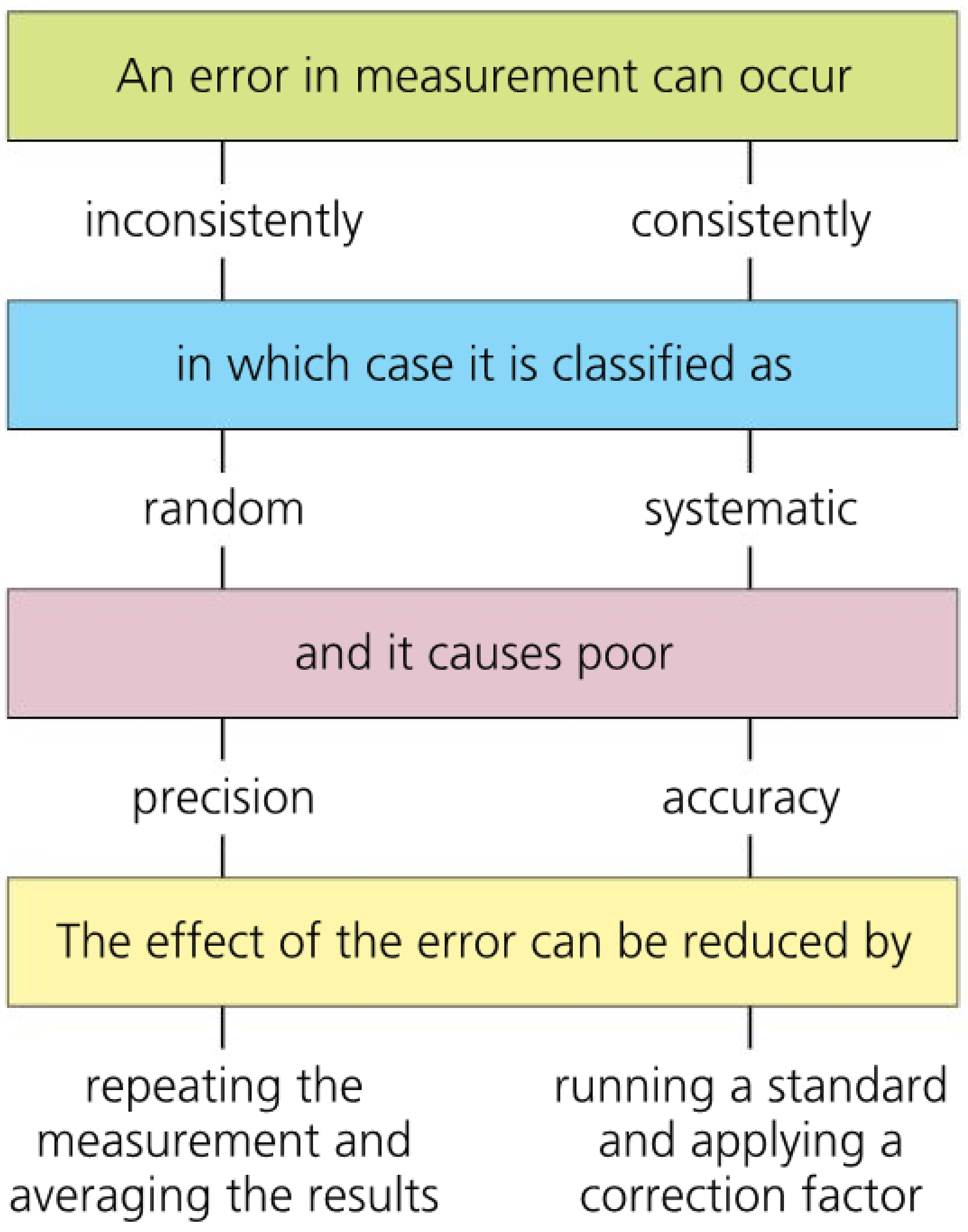


Figure 14.4 Concept chart contrasting random and systematic errors

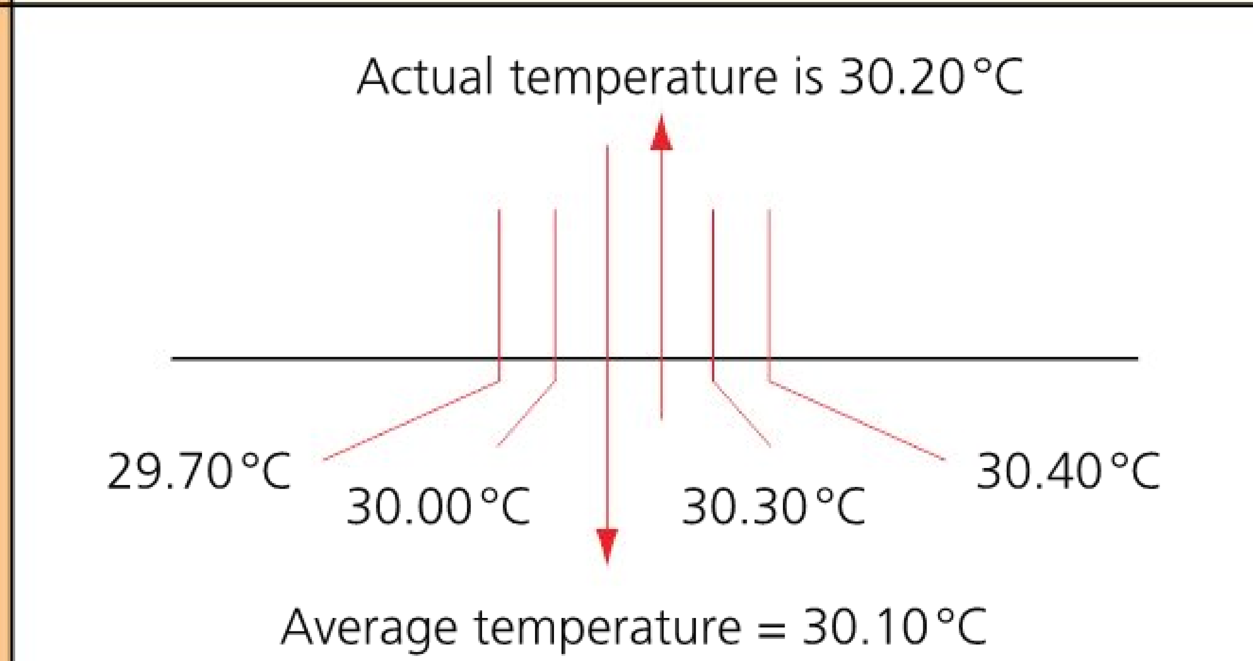
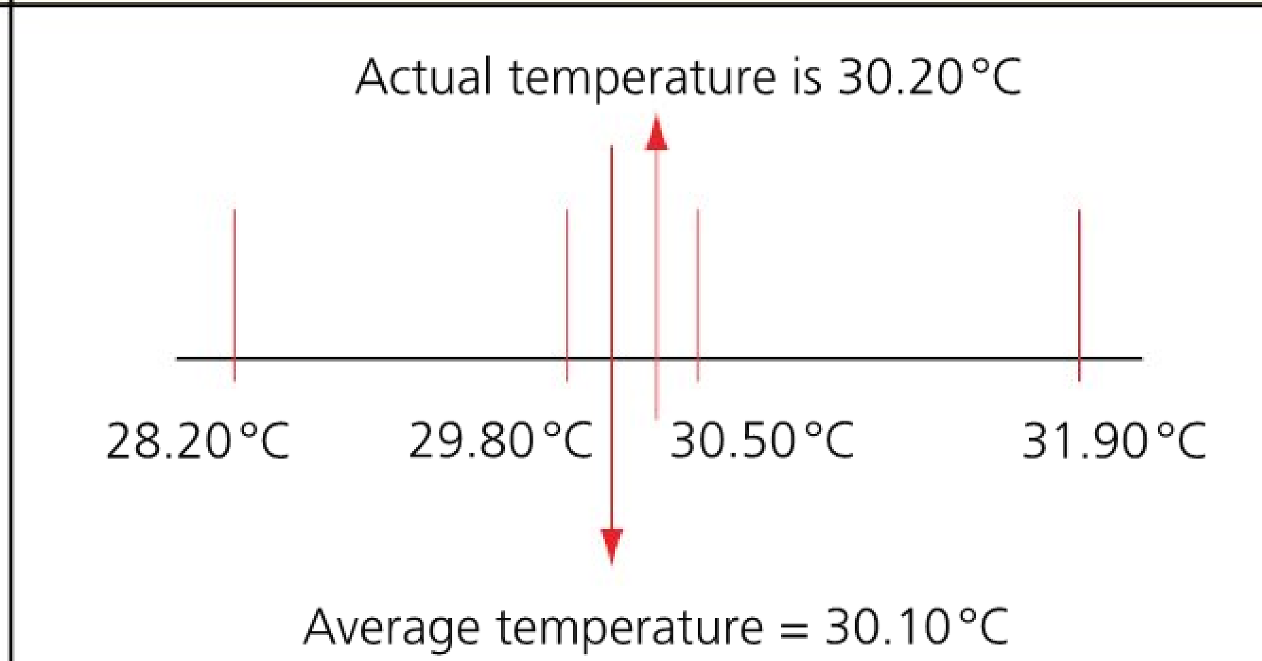
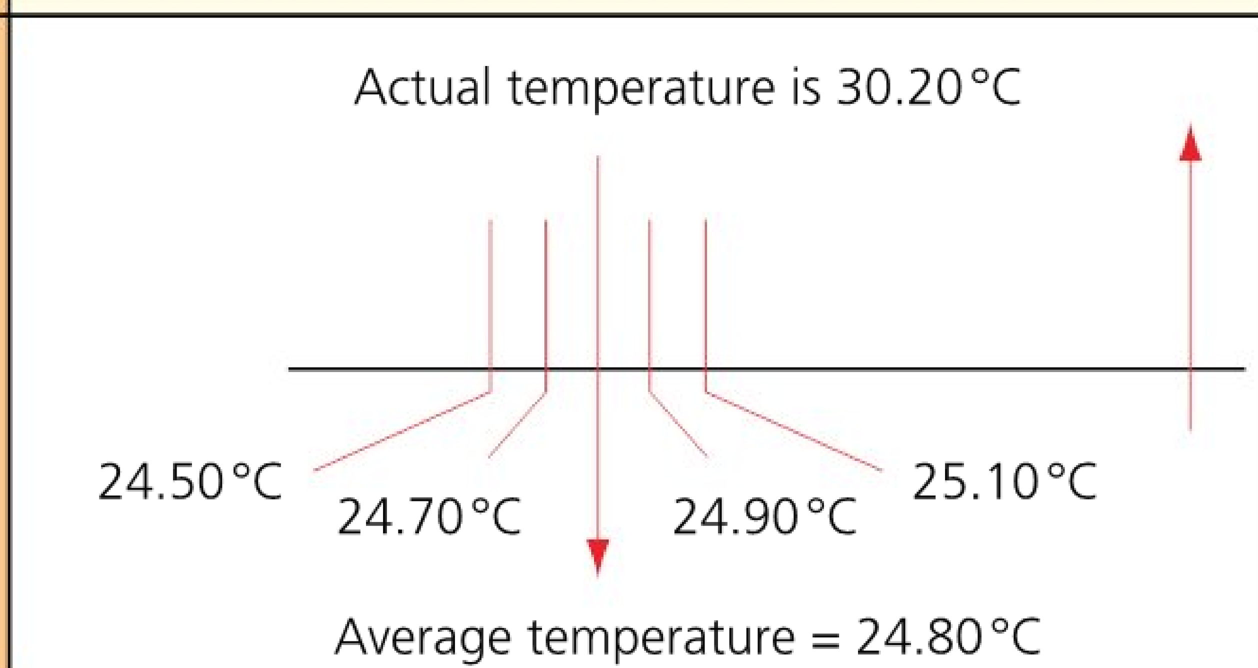
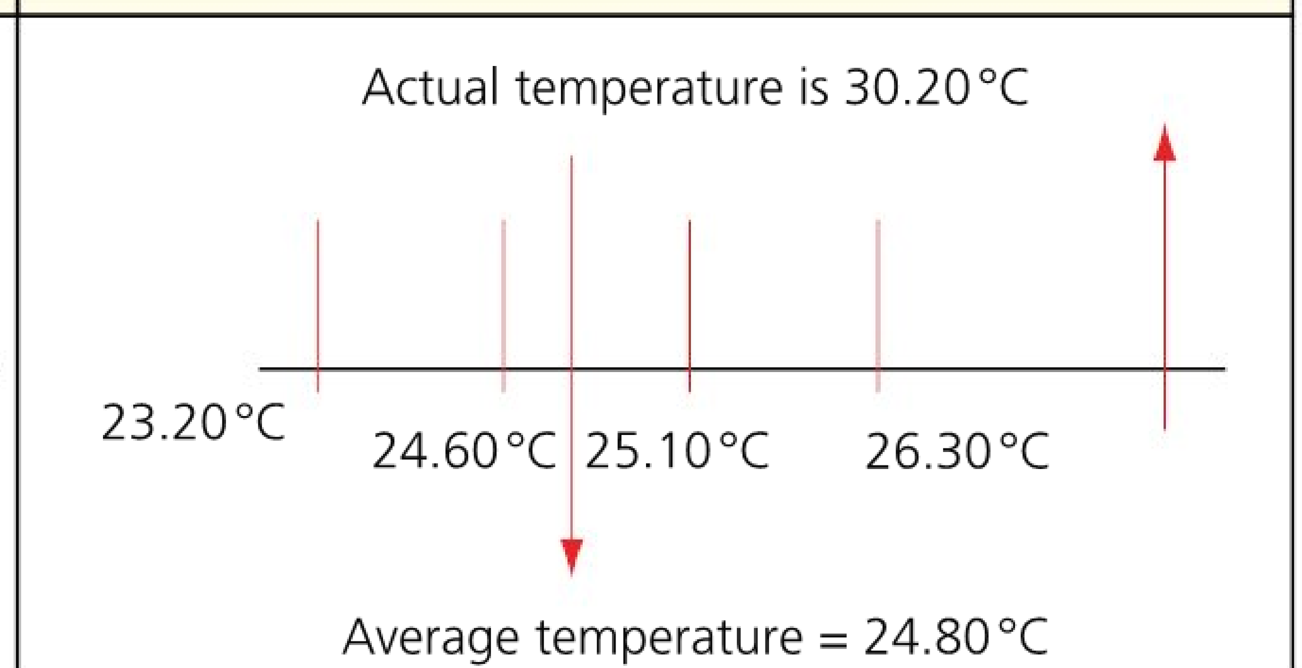
Example		2
Random error	Small	Large
Systematic error	Small or negligible	Small or negligible
Diagram		
Remarks	Precise and accurate	Not precise but accurate
Example	3	4
Random error	Small	Large
Systematic error	Large (below actual value)	Large (below actual value)
Diagram		
Remarks	Precise but inaccurate	Not precise and inaccurate

Figure 14.5 Examples of random and systematic error in temperature measurements

Calculating percentage error for independent and dependent variables

In your analysis section, you need to, if appropriate, calculate uncertainties (percentage errors) for both independent and dependent variables (uncertainties cannot be calculated if data are categorical or are counts of organisms), so that you can discuss the impact of these uncertainties in your conclusion and evaluation.

To estimate the uncertainty of your data, take the smallest value in your data set and calculate the percentage error of this value. The percentage error will be largest at this value, and so if this is not significant, the error in larger values is likely also to be not significant:

(error ÷ smallest value) × 100

- By using smallest measured value, any uncertainties will be at their largest effect.
- For example, if measuring leaf length, absolute error = 0.5 mm, so if smallest value is 40 mm, percentage error = $\left(\frac{0.5}{40}\right) \times 100 = 1.25\%$.
- Any uncertainty <10% is unlikely to be significant (although the significance of an error depends entirely on the degree of accuracy that is being aimed for).

Table 14.2 shows absolute errors for some common apparatus used during ecological investigations.

Apparatus	Uncertainty (absolute error)
Oxygen probe	± 0.4 mg l
Hygrometer (relative humidity)	± 5% rh (± 5% of relative humidity measure)
Anemometer (wind speed)	± 5% $m\,s^{-1}$
Digital thermometer	± 0.1 °C
Digital balance	± 0.2 g
Light meter (lux)	2000 ± 0.5 20 000 ± 5 200 000 ± 50
pH probe	± 0.1
Flow meter	± 1.5% m s
Non-electronic apparatus	± 0.5 × smallest unit of measurement

Table 14.2 Absolute errors of ecological apparatus. Some errors are expressed as units and others as a percentage of the data value recorded

Interpretation of processed data

You need to interpret your processed data correctly, for example, you should be able to deduce from a graph the correct graphical relationship between the independent and the processed dependent variable, and quote data to support your ideas. You should also analyse the results of any statistical tests you have carried out (see Chapter 9), if appropriate. The interpretation of the data can be presented after each data set.

Expert tip

Certain plot shapes are easily associated with models that make it easier to suggest causal mechanisms. For example, a bell-shaped curve is associated with random samples and normal or Gaussian distributions; a concave, increasingly upward curve is associated with exponentially increasing functions, such as the early stage of population growth; an S-shaped curve is associated with a carrying capacity of the environment (a logistic curve); and a sine-wave-like curve is associated with a predator-prey cycle.

Expert tip

Bell-shaped curves, relating to normal distribution around a mean value (see page 120) only apply when plotting the distribution of a single variable (i.e. a histogram), not line graphs or bar charts.

Conclusion

You must state a conclusion based on the outcomes from your investigation. Conclusions need to be supported by the data and explanations included. You must refer back to your research question at this point in the report. An environmental context is needed for a full discussion.

The conclusion should focus on how the independent variable affects the dependent variable.

Expert tip

In a statistical analysis, if there is no significant result then discuss the possible effects of the monitored variables on the dependent variable.

When analysing data and drawing conclusions:

- The data analysis you used must be appropriate to the focus of the investigation and help you to address the research question.
- Conclusions must be based on direct evidence from the data and not on unqualified assumptions.

In this section you are making deductions based on direct interpretation of your data. This is what is meant by the term 'conclusion'. For example, in this section you will explain what your graphs indicate, and whether any statistical test you may have carried out supports your conclusion.

Any variability in the data should be established and explained, and its extent and impact on the conclusion recognized. Variability in the data should lead to a cautious conclusion, aiming to identify patterns or trends rather than looking to establish causal links.

Expert tip

An overview of the data in light of the broader context is assessed in the Discussion and evaluation criterion that follows this section.

Results, analysis, conclusion criterion checklist

Recording raw data

Descriptor	Complete
You neatly record all raw data: qualitative data (observations) and quantitative (numerical) data necessary to support a conclusion to the research question.	
You present all raw numerical data clearly and correctly in tabulated manner (for example, independent variable on far left, then dependent variable followed by processed variable). SI units are typically used.	
The headings in your data tables have labels, units and uncertainties (absolute errors) once in the headings.	
You consistently record quantitative data taking into account the absolute uncertainty/error (correct number of decimal places).	
You describe how the absolute uncertainties in the measurements were obtained, for example, half of the least count of the scale, smallest number on digital display, or manufacturer's tolerance.	
You clearly indicate and highlight any anomalous data, that is, outliers (and statistically justify its exclusion, if appropriate).	
Your processed data resolves the research question.	

Processing raw data

Descriptor	Complete
You use the appropriate formulas and annotated mathematical equations to carry out calculations to process raw data (for example, means, medians, modes, standard deviation, range, rates, percentage change or logarithms (to base 10 or *e*)).	
You record results of calculations according to the rules of significant figures, that is, decimals are consistent for data.	
You convert the appropriate averaged data into the correct graphical form: line graph, scatter graph, bar chart, etc.	
Where relevant you select appropriate processed average data to produce a straight-line graph (if data are continuous) (with line of best fit: graphically or computer generated).	
You process replicate data – finding the mean and using the variation between values to assign an appropriate uncertainty.	
Statistical test (if appropriate)	
Statistical test identified and its justification explained.	
Hypothesis and null hypothesis stated.	
Accurate processing of data for statistical test present.	
Result of statistical test clearly stated.	
Comparison of statistical test result to critical value present.	
Clear and correct statement as to whether the hypothesis is accepted or rejected.	

Presenting processed data

Descriptor	Complete
All relevant patterns are displayed.	
You use scientific conventions in tables of processed data.	
You use accepted conventions for graphs, for example, title, correct graph size (large), appropriate range and scale, labelling, units, etc.	
Your line graphs, bar graphs, histograms, scatter graphs, or box-and-whisker plots have the independent variable on the *x*-axis; dependent variable on the *y*-axis.	
You draw the line or curve of best fit correctly and clearly indicate the trend shown for line graphs.	
You include error bars on line graphs, where appropriate and possible.	

Impact of uncertainty

Descriptor	Complete
You convert absolute uncertainties to percentage errors. Calculation of percentage error for at least one value of the independent variable and dependent variable (where appropriate).	
You present calculations in a clear, organized and separate manner.	
You present final values with the number of decimal places consistent with the uncertainty.	
You explain the impact of measurement uncertainty relating to the independent variable and dependent variable (where appropriate).	

Interpreting processed data

Descriptor	Complete
Trends, patterns or relationships in the data are identified so that a valid conclusion to the research question can be deduced.	
The processed data is correctly interpreted, for example, the correct graphical relationship between the independent and the processed dependent variable is deduced from a graph with data quoted to support it.	
Analysis of the correct statistical test is carried out, if appropriate.	

Conclusion

Descriptor	Complete
You include a detailed conclusion (for example, trend between independent and dependent variables) citing numerical values relevant to the research question.	
Your conclusion is in accordance with the statistical test result, explanation and impact of any measurement uncertainties.	
Your conclusion is supported by the raw and processed data (typically diagrams, graphs or charts) and the observations.	
Statement of the result of the statistical test present, including significance, if relevant.	
You include a conclusion that is described, justified and compared to the relevant biological literature (if available).	

15 Discussion and evaluation

In this criterion you need to discuss your conclusion in the context of the environmental issue and carry out an evaluation of the investigation. You are expected to see how your conclusion measures up against what might be known regarding the environmental issue.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
1–2	The student's report: • **describes** how some aspects of the conclusion are related to the environmental issue • **identifies** some strengths and weaknesses and limitations of the method • **suggests** superficial modifications and/or further areas of research.
3–4	The student's report: • **evaluates** the conclusion in the context of the environmental issue but there are omissions • **describes** some strengths, weaknesses and limitations within the method used • **suggests** modifications and further areas of research.
5–6	The student's report: • **evaluates** the conclusion in the context of the environmental issue • **discusses** strengths, weaknesses and limitations within the method used • **suggests** modifications addressing one or more significant weaknesses with large effect and further areas of research.

Source: © IBO 2015

Table 15.1 Mark descriptors for the discussion and evaluation criterion

This criterion requires you to **reflect** on your study. The results of any research project will be influenced by limitations, and the focus in this section is to identify these and to reflect on how they have impacted your conclusions. Points you need to consider are:

- What were the strengths, weaknesses and limitations of your research methodology?
- Did any weaknesses of the experimental design emerge as a result of carrying out the study?
- How do the outcomes of your investigation relate to the broader environmental issue introduced at the beginning of your IA?
- To what extent do your results support or contrast with information from established literature on the subject of your study?
- What reasons can you suggest for any similarities or differences between your results and previous published studies?

In this criterion, the focused research question is widened to readdress the broader environmental issue.

The first aspect of this criterion (the first bullet point in Table 15.1 above) is a new skill and asks you to evaluate the conclusion in the context of the environmental issue. Points to think about in this section include:

- Is your conclusion in keeping with the literature?
- If it is in keeping with the literature, is it a reliable conclusion?
- Are standard deviations small or large? Limited variation in the data suggests that your conclusions are valid, whereas larger variations may lead you to be more cautious in supporting your conclusions.

You need to discuss the strengths and weaknesses and not just provide a description of them.

Expert tip

The validity of the data must be assessed as part of the conclusion; evaluation of the methodology must be assessed in the discussion criterion.

Common mistake

Candidates often rush this section, even though it is worth 6 marks, perhaps due to time constraints or a lack of understanding of what is needed. The first and second aspects of this criterion (the first two bullet points in the table above) require you to evaluate and discuss – this is difficult to do successfully in one brief paragraph or in a table format.

Common mistake

Candidates struggle with the first aspect of the discussion and evaluation criterion, finding it difficult to evaluate the conclusion in light of the environmental issue. If you do not mention the environmental issue in this criterion, and what your results suggest about it, you cannot score full marks.

Strengths and weaknesses of the investigation

The methodology must be evaluated thoroughly. You need to include the strengths as well as the weaknesses of the investigation. For example, a strength could be a small standard deviation in data for the dependent variable, indicating that measurements were precise. Weaknesses could include instances where other variables in an investigation were not sufficiently controlled, or if using an online simulation the software might not have accurately reproduced natural conditions (such as the natural selection simulation discussed on pages 141–142). Do not just restrict weaknesses to details of the practical, but include other aspects as well (for example, lack of secondary data or literature values for comparison).

Expert tip

A table of strengths and weaknesses may provide a useful scaffold for some candidates (see Tables 15.2 and 15.3), but it is difficult to achieve full marks using this approach because these pros and cons are only described, not discussed. If such a table is used, it needs to be accompanied by text, describing the points made.

Strengths	Implications for your investigation

Table 15.2 Evaluating the strengths of an investigation – such a table must be accompanied by text which explains the points made

Weakness/limitations	Implications for your investigation

Table 15.3 Evaluating the weaknesses of an investigation – such a table must be accompanied by text which explains the points made

Limitations of the data and sources of error

In this part of the report you can discuss uncertainties (percentage error) of dependent and independent variables (see pages 162–164). The impact of the limitations on the conclusion must be discussed. Your report needs to propose improvements, and these must be realistic and specific.

Expert tip

In an ecological study, focus your evaluation on the limitations of independent and dependent variables, and sampling methodology, rather than monitored variables, because these are central to your research question, and link specific improvements to them.

Improvements and extensions

The final part of this criterion requires you to suggest both modifications and further areas of research. You need to discuss how you could avoid the limitations you have outlined. You also need to suggest an extension to the work you have carried out: this must follow on logically from your investigation. Extensions need to be quantitatively different from what has been done in the investigation and not just be 'more of the same' (that is, simply repeating the same experiment with a greater frequency of independent or dependent variable); instead, a significant extension is required, such as a different dependent variable, different species studied, and so on. For example, if measuring how the amount of traffic in different parts of your neighbourhood affects the tropospheric ozone level near the ground, an extension could be gathering data on the types of vehicle, over a wider area of the city.

Expert tip

In your evaluation, make sure you:

- discuss the strengths of your investigation – these might be general or might refer to specific parts that worked well
- discuss the reliability of the data
- identify weaknesses in the method, apparatus and instruments
- evaluate the relative impact of a weakness on the conclusion.

Discussion and evaluation criterion checklist

Discussion

Descriptor	Complete
Your conclusion is evaluated in the context of the environmental issue.	
You identify and comment on any anomalous data.	
You justify your results with reference to relevant environmental models, theories and principles.	
You discuss limitations to your results.	

Evaluating procedures: strengths and weaknesses

Descriptor	Complete
You describe strengths within the method.	
You describe assumptions that were made which have affected the accuracy of the results, for example, all organisms behave the same under the experimental conditions, negligible mortality during the experimental period.	
Limitations of the data associated with the method are described. Sources of error associated with the method are discussed.	
You identify systematic errors and their directional effect on the experimental result (increase or decrease).	
You discuss any limitations of the method, for example, limited data range, limited instrument sensitivity, and sample size.	

Improving and extending the investigation

Descriptor	Complete
Specific modifications/improvements relating to the limitations and errors stated above are given.	
You suggest appropriate modifications in the steps taken to improve the accuracy, precision and reliability of the results (by reducing random and systematic errors) or better control/monitoring of controlled variables.	
You suggest a reasonable alternative method or different instrumentation to obtain the same experimental data, or more accurate data.	
You discuss clearly how the suggested improvements or modifications would improve the reliability, precision and accuracy of the results.	
You propose realistic and relevant extensions to the study, for example, new data processing/data presentation, choice of new independent variable.	
Your suggested improvements are focused on the existing research question.	
Your extensions are focused on a new research question.	

16 Applications

In this criterion you need to outline one way you could apply the outcomes of the investigation in relation to the broader environmental issue. It measures your ability to apply your research, at least as a thought experiment.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
1	The student's report: • **states** one potential application and/or solution to the environmental issue that has been discussed in the context • **describes** some strengths, weaknesses and limitations of this solution.
2	The student's report: • **describes** one potential application and/or solution to the environmental issue that has been discussed in the context, based on the findings of the study, but the justification is weak or missing • **evaluates** some relevant strengths, weaknesses and limitations of this solution.
3	The student's report: • **justifies** one potential application and/or solution to the environmental issue that has been discussed in the context, based on the findings of the study • **evaluates** relevant strengths, weaknesses and limitations of this solution.

Table 16.1 Mark descriptors for the applications criterion

In this criterion you must reflect on the results of your study in the light of your broader environmental issue, and create new ideas based on research findings:

- What do your results tell you about the environmental issue you are exploring?
- Can you suggest and justify a potential solution to one aspect of the environmental issue, based on the results of your study?
- How do your data support the solution you are proposing? What are the strengths and limitations of your proposal?

Common mistake

In the applications criterion, candidates sometimes are too general and do not include an evaluation. If writing about the effects of photochemical smog, for example, it is not enough simply to state that governments could pass legislation to reduce the emissions involved: examples of successful applications of legislation are needed and the successes (or otherwise) evaluated.

This section requires one well thought-out application with an evaluation of the strategy, examining both pros and cons. It is not necessary to provide several applications – only one is needed. For example, if your IA is investigating the effect of black carbon air pollution on the urban heat island effect, an application could be the promotion of green buildings, for example, green roofing, where the use of reflective paint on buildings and roofs increases the albedo and so reflects solar/infrared energy away from the urban area rather than it being absorbed. An evaluation of this strategy would be:

- The reflective surface should stop the black carbon easily sticking and make it simple to wash or blow off.
- Limitations of the solution would be that it can only work well where construction of new building is taking place, and to change buildings to a more sustainable design will incur additional costs, and there could be the significant issue of who would pay. Also, where there are historical or culturally significant buildings, people might not want to change the structure and appearance.

- In many hot or tropical countries, the use of white limewash on buildings has been used over a long period of time. It may be straightforward to encourage the reintroduction of old practices.
- Although this solution might help reduce urban heat islands, the reflection of heat may still have consequences for air heating the atmosphere in other ways. Urban heat islands are complex systems and there may therefore be further consequences of making this one change.

Expert tip

The solution does not need to be based directly on the data generated by the study – this is in recognition that the results may be unclear or confusing and this should not have a knock-on effect on the applications.

Expert tip

Your suggestion may be based on the local context of your study or be more widely relevant – this will depend on the nature of your initial research question and the quality of the data obtained.

Applications criterion checklist

Descriptor	Complete
You discuss and justify one potential application and/or solution to the environmental issue (as identified in the context of the IA).	
Your application/solution is based on the findings of the study.	
You explain the relevant strengths, weaknesses and limitations of the application/solution.	

17 Communication

This criterion assesses whether your investigation is presented and reported in a way that supports effective communication in terms of structure, coherence and clarity of the focus, process and outcomes.

Your report must be word processed, page numbered and any equations should be embedded in the text of your report and formatted using the 'Equation Editor' tool in your word processor (Figure 17.1)

Expert tip

You will be penalized if your report exceeds the given word limit in this criterion because it indicates that you have not been concise enough.

Figure 17.1 Equation Editor toolbar in Microsoft Word running on an i-Mac

Your report should be between 1 500 and 2 250 words in length, including any index or title page.

Achievement level	Descriptor
0	The student's report does not reach a standard described by any of the descriptors given below.
	• The investigation has limited structure and organization. • The report makes limited use of appropriate terminology and it is not concise. • The presentation of the report limits the reader's understanding.
	• The report has structure and organization but this is not sustained throughout the report. • The report either makes use of appropriate terminology or is concise. • The report is mainly logical and coherent but is difficult to follow in parts.
3	• The report is well structured and well organized. • The report makes consistent use of appropriate terminology and is concise. • The report is logical and coherent.

Source: © IBO 2015

Table 17.1 Mark descriptors for the communication criterion

This criterion assesses whether you have clearly communicated the findings of your study:

- A clearly written and logically presented report should not need to be reread. Can the report be read by a friend or your teacher without them needing to reread any part of it?
- Are the information and explanations targeted at your research question? Your report should not just be a general discussion of the subject area but should be focused on the research question and specific context you have decided to study.
- Is the vocabulary you have used subject specific and of an appropriate quality? Think about specific terms you have used in ESS – you must apply them here.
- Have you used the correct formats for graphs, charts, data tables and headings? Have you used the correct units throughout?

Expert tip

Marks for the communication criterion take the entire report into account.

While the report would be expected to be correctly referenced, you may not be penalized under this criterion for a lack of bibliography or other means of citation. It is likely that such an omission would be treated under the IB Diploma Programme academic honesty policy.

Failure to follow conventions, such as poor titles in tables, including units in individual cells in tables rather than only having them in column headings, lack of vertical and horizontal axes labels in graphs, may result in lower marks for this criterion.

Expert tip

There is no requirement that the report is organized according to the headings of the criteria, although they do provide a useful framework for your report.

Common mistake

Candidates may lose marks for lack of attention to detail in labelling graphs, tables, diagrams, or having a lack of scale in photographs or maps.

Structure and clarity

The presentation must be coherent and relevant to the focus (the research question and the process (the methodology)) and the outcomes (results and conclusion). Ideally there should be headings and subheadings to give a logical sequence to the individual investigation report. Diagrams and digital images should be used to enhance understanding, with suitable referencing. There should be a logical flow to your report allowing the IB examiner to understand your thought processes throughout the report. The description of your methodology should be detailed enough for the experiments to be reproducible, but simplistic, well-known and assumed aspects of your method need not be made explicit. No appendix should be included – it will not be read and will reduce your available word count.

Examiner guidance

Candidates should not add appendices in addition to the total word count and should not send in excessive quantities of raw data from data loggers.

Relevance and conciseness

Your written work, including the background information, should remain closely connected to and relevant to the research question and topic of your individual investigation. It should be easy for the IB examiner to follow the development of your ideas and thoughts from the beginning to the end of your report. It should be concise with no unnecessary or repetitive (redundant) information. Your report should be between 1 500 and 2 250 words in length, including any index or title page. There are no automatic penalties for a report that is slightly longer, as long as it remains relevant and concise throughout.

Full calculations for processing of all numerical data are not expected – selected examples will be sufficient and free up more space for your conclusion and evaluation.

Make sure that tables of raw data are not repetitive, and use only one if this is the best way to present data. Similarly, avoid repetitive data tables when one would suffice. If you have drawn several graphs, it may be appropriate to combine them rather than display multiple graphs – this will not only save space but also allow you to draw comparisons between data.

If you have produced a graph from data logging which is then used to derive a value such as a rate, one example can be presented to explain the processing and then the rates derived can be organized in a table.

Expert tip

The communication statement *The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation* is more likely to be met by a report of about 1 500 to 2 250 words long.

Common mistake

The following are often included but are not necessary: using whole pages for titles or contents; presenting blank data tables at the end of the method section.

Terminology and conventions

Pay close attention to the use of specific terminology (especially IB ESS terminology) and scientific conventions, for example, letters in mathematical equations italicized, correct units used, appropriate number of significant figures, and binomial species names underlined or italicized.

Examiner guidance

Remember that in any mathematical equation the units must balance on the two sides. For example, $0.08\ \text{cm}^3/2\ \text{s} = 0.04\ \text{cm}^3\ \text{s}^{-1}$ and $4.0\ \text{cm} \times 4.0\ \text{cm} = 16.0\ \text{cm}^2$. It is good practice to include all units in calculations, or at least in one sample calculation.

Your report needs to reference material via footnotes, endnotes or in-text citations. A full bibliography should be included at the end of the report.

Metric units should be included throughout the report. The numbers of decimal places should be consistently applied and correspond to the precision of the data. Measurement uncertainties should be included.

SI units should typically be used, with the exceptions of mass (grams) and volume (cubic decimetres and cubic centimetres).

Common mistake

The format of scientific names is sometimes incorrect, for example, having a capital letter for species name rather than the correct lowercase letter; species names need to be presented in italics or underlined, for example, *Echium vulgare* or <u>Echium vulgare</u> not Echium vulgare or Echium Vulgare.

All tables, graphs and equations should be introduced by a sentence of explanation. They should also have an explanatory label. The labels should be applied using the same formatting and numbered sequentially throughout the report, for example, equation (1).

SI units

You are normally expected to use the following units for recording measurements and in associated calculations during the course of the practical work carried out to support the IB ESS Programme. Recorded measurements should always include the relevant units (Table 17.2).

See also pages 10–12 for information about correct units to use in your report.

Quantity	Unit
Concentration	Moles per cubic decimetre, mol dm^{-3} or gram per cubic decimetre, g dm^{-3}. Parts per million can also be used (ppm)
Energy	Joule (J)
Mass	Gram (g)
pH; absorbance	No units (because they are logarithmic functions)
Temperature	Standard thermometers measure temperature in degrees Celsius (°C)
Time	Seconds (s) (unless time intervals are long)
Volume	Cubic centimetres (cm^3) or cubic decimetres (dm). Measurements using laboratory apparatus will commonly be in cm^3, while concentrations are expressed in terms of dm^3

Table 17.2 Quantities and their associated units

Referencing

Referencing is an internationally or nationally standardized method of acknowledging the sources of information you have consulted when writing your individual investigation report. All words, paragraphs, quotes, figures, tables, charts, digital images, theories, scientific ideas and facts originating from another source and used in your individual investigation report must be referenced (that is, acknowledged). Referencing is done for the following reasons:

- to avoid plagiarism (that is, to avoid presenting someone else's work as your own)
- so that your teacher can verify quotations
- so that your teacher can follow up on your thinking by consulting the source you accessed.

There are many ways to acknowledge sources of information, for example, MLA (Modern Language Association), APA (American Psychological Association), Chicago, ACS (American Chemical Society), and Turabian: none is mandated by the IBO, though your school might dictate a referencing style that you must adopt. APA tends to be used by Psychology and the Sciences. Make yourself familiar with the school's requirements for referencing and citation. Be consistent and familiarize yourself with the format and terms that your school or IB ESS teacher expects you to use.

For example, the ACS style (shown below) has a citation consisting of two parts: the *in-text citation*, which provides brief identifying information within the text, and the *reference list*, a list of sources that provides full bibliographic information. In the ACS style the in-text citations can be referenced by superscript numbers, italic numbers or author name and year of publication.

Book
Davis, A.J.; Nagle, G.E. *Environmental Systems and Societies Study and Revision Guide for the IB Diploma*; Hodder Education, 2017.

Journal article
Turner, I.M., 'Species loss in fragments of tropical rain forest: a review of the evidence'; *J. Appl. Ecol.*, 1996, Volume 33, 200–209.

Website

Perritano, J. Scientists discover caterpillar that actually eats plastic; https://animals.howstuffworks.com/insects/scientists-discover-caterpillar-that-actually-eats-plastic.htm (accessed May 4, 2017).

Assessing sources

Before you decide to use some source material, ask yourself these questions:

- Can you identify the author's name?
- Can you determine what qualifications or titles he/she has?
- Do you know who employs the author, such as a university or company?
- Is this a primary source (original research paper) or a secondary source (for example, a review article?)?
- Is the content original or derived from other sources?

Expert tip

References are required in both background information (identifying the context), conclusions (results, analysis and conclusion), and discussion (discussion and evaluation). Have other people done similar work to yours that you can refer to? Does your information need referencing?

Evaluating information

It is important that you check the validity of the sources you are using. Do not assume that information is correct. The following checks can be made to ensure that the sources you use for your individual investigation provide you with accurate information:

- Have you checked a range of sources?
- Is the information supported by relevant literature citations?
- Is the information taken from a credible source (for example, a peer-reviewed journal, such as 'Trends in Ecology and Evolution', 'Journal of Applied Ecology', 'Journal of Biogeography')?
- Is the age of the source likely to be important regarding the accuracy of the information?
- Is the source information scientific fact, opinion or speculation?
- Have you checked for any mistakes or inconsistencies in the arguments?
- Have the errors associated with any measurements been taken into account?
- Have the data been analysed (if appropriate) using relevant statistics?
- Are the data in graphs displayed fairly?

Expert tip

Scientific papers submitted to peer-reviewed journals, such as 'Nature', are carefully scrutinized by experts in the field ('peers') to ensure that the arguments, results and analyses presented are legitimate and worthy of publication. Information from such sources can be trusted as being scientifically valid.

Report format

There is no particular structure that you must follow for your individual investigation report, though it should resemble a research paper (without the abstract). If your school does not suggest a format, then you could use the following headings, or simply use the assessment criteria:

- General title or aim
- Environmental issue
- Background information
- Environmental theory and hypothesis (if appropriate)
- Research question
- Risk assessment
- Planning and preliminary experimental work
- Classification of variables
- Methodology
- Statistical test
- Raw data
- Processed data (including graphs, charts and statistical analysis)
- Conclusion

- Discussion
- Evaluation:
  - Random and systematic errors
  - Impact of measurement uncertainty
  - Limitations, weaknesses and improvements
  - Comparison with secondary sources
- Future extensions to the investigation
- Bibliography of references.

Use Figure 17.2 to check that you have covered all aspects of each criterion.

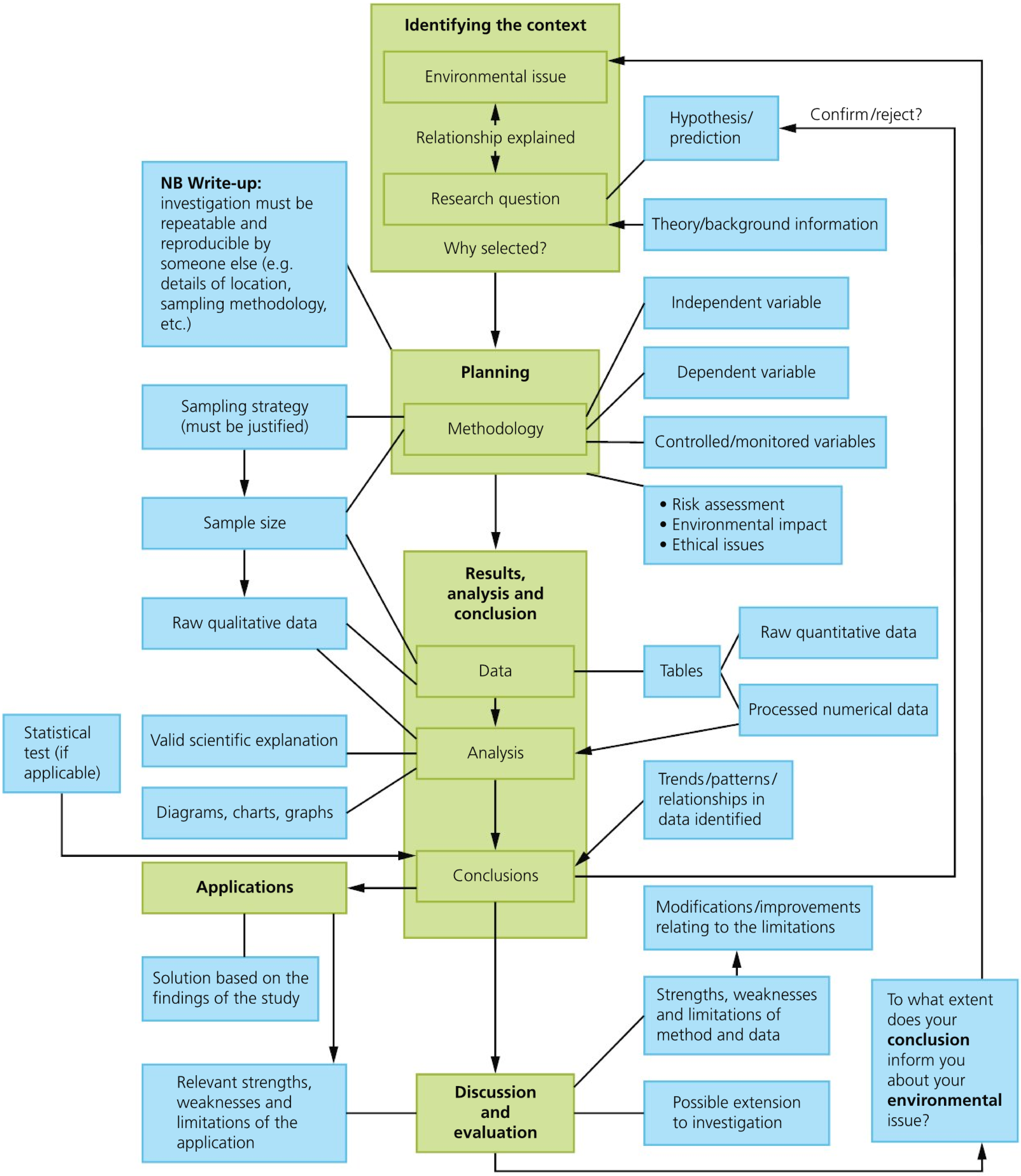


Figure 17.2 ESS individual investigation map

Expert tip

Carefully check your individual investigation report:

- The report has a structure which is clear, well organized, and easy to follow, for example, sections are clearly and helpfully headed.
- The report is logical and coherent.
- The report makes consistent use of appropriate terminology.
- The report is concise (between 1 500 and 2 250 words long).
- A sensible stance has been taken regarding font size and margin width, to ensure that good communication skills are demonstrated.
- Conventions have been followed in the presentation of tables, charts and graphs.
- Published works have been referenced correctly, with a suitable bibliography/reference list included.

Expert tip

Get a friend to read through and check your report. Do the ideas flow logically, is the use of independent and dependent variables consistent (in research questions, summary of variables), etc.?

Using tenses when writing a report

When you write your report, you need to choose which tense to use.

Introduction
This is usually presented in the present tense, for example, *transect studies provide important information for ecological investigations*. When you are using the present tense you are indicating to the examiner that you believe the research findings are true and relevant, even though they were carried out in the past.

Methodology
It is usual practice (but not an IB requirement) to use the simple past tense with the passive voice to describe your fieldwork or experiments. For example, *ten quadrats were placed along the transect*.

Results
Results are usually described using the past tense. For example, *five samples of water, collected from locations in polluted and unpolluted areas, were analysed with an oxygen probe so that the levels of Biological Oxygen Demand (BOD) could be recorded – levels of dissolved oxygen were measured over a given period of time in water samples at a specified temperature*

Further discussion on this topic and additional examples can be found on the following website: **http://services.unimelb.edu.au/__data/assets/pdf_file/0009/471294/Using_tenses_in_scientific_writing_Update_051112.pdf**

Academic honesty

You need to ensure that the individual investigation report you submit for your internal assessment (IA) is your own work. At the end of the course you will need to sign a declaration to that effect. Throughout the course (and not just in internal assessment), your IB ESS teacher is required to ensure that any submitted work is your own.

When in doubt, your IB ESS teacher will check the authenticity of your work by:

- discussing it with you
- asking you to explain the method and to summarize the results and analysis
- asking you to repeat an investigation
- using software (such as **turnitin.com**) to check for plagiarism.

If you use any experimental method from another source then you need to ensure that you acknowledge it. This also applies if you use diagrams, tables, charts, graphs, literature values from the internet or reference books. Each lab report should have a bibliography acknowledging the sources used.

Plagiarism

Plagiarism is defined (by the IBO) as the representation, intentionally or unwittingly, of the ideas, words or work of another person without proper, clear and explicit acknowledgment.

Figure 17.3 Never 'copy and paste' information – read and rewrite (or redraw if a figure) in your own words

Academic honesty and integrity are consistent with the IB learner profile (Introduction, page xiii), where learners strive to be principled. The IB upholds principles of academic honesty, which are seen as a set of values and skills that promote personal integrity and good practice in teaching, learning and assessment.

Examples of plagiarism include:

- copying the work of another IB ESS student (past or present) and passing it off as your own work
- using 'essay-writing' services, such as those available online or from a tuition centre
- copying text or images from a source (book chapter, journal article, or website, for example) and using this within your report without acknowledgement
- quoting others' words without indicating who wrote them or said them (personal communication)
- copying scientific ideas and concepts from a source without acknowledgement, even if you paraphrase them.

Expert tip

The following suggestions will help you to avoid plagiarism:

- Make sure the work (results and theory) you present in your individual investigation report is always your own.
- Never 'copy and paste' from websites or Word or PDF files downloaded from the internet.
- Place appropriate citations in your report, where required or appropriate.
- Show clearly where you are quoting directly from a source.

Communication criterion checklist

Descriptor	Complete
Structure of report	
Your report is well structured, coherent and clear.	
The report has a structure which is clear, well organized, and easy to follow, for example, sections are clearly and helpfully headed.	
Relevance and conciseness	
Your report includes only relevant information, is concise and between 1 500 and 2 250 words in length.	
Your report does not contain any errors, contradictions, false statements or false assertions.	
Subject-specific terminology and conventions	
You have used appropriate terminology throughout the report.	
Your graphs, tables, charts and images are fully titled and referenced and presented according to conventions in journals.	
Your mathematical equations are in italics and clearly explained and justified/derived (where appropriate) with units.	
You have followed the rules relating to significant figures. The number of decimal places is correct in data tables and calculations.	
You have defined non-syllabus terms and abbreviations.	
Your report includes a cross-referenced bibliography with in-text referencing according to a particular referencing style.	

Glossary

Abiotic – the non-living components of an ecosystem.

Abiotic factor – a non-living physical factor that can influence an organism or ecosystem, for example, temperature, sunlight, pH, salinity or precipitation.

Absolute humidity – the actual amount of moisture held by a cubic metre of air.

Absorbance – a measure of the light absorbed by the sample that does not reach the detector. It is proportional to concentration of dissolved solute.

Accuracy – how close to the true value a result is.

Albedo – the reflectivity of a surface.

Analysis/analyse – break down in order to bring out the essential elements or structure.

Anomalous data – data with unexpected values that do not match the relationship predicted by the hypothesis.

Bias – when results are shifted in a particular direction by a systematic error.

Biochemical oxygen demand – a measure of the amount of oxygen required to break down the organic matter in a given volume of water through aerobic biological activity.

Biodiversity – the amount of biological or living diversity per unit area. It includes the concepts of species diversity, habitat diversity and genetic diversity.

Biomass – the mass of organic material in organisms or ecosystems, usually stated per unit area.

Biome – a collection of ecosystems sharing similar climatic conditions – for example, tundra, tropical rainforest, desert and coral reef.

Biotic – the living part of an ecosystem (the community).

Biotic factor – a living physical factor, such as a species, population or community, that influences an ecosystem.

Biotic index – the use of animal species to make conclusions about the level of pollution.

Birth rate – the number of live births in a population per 1000 people per year.

Calibration – aligning a measuring instrument's scale with known points or values.

Climate – the extremes and average of weather conditions for an area over a time of not less than 30 years.

Climate change – the human-induced changes to the world's climate, also known as the enhanced greenhouse effect.

Colorimeter – an instrument for measuring the absorbance of a solution using visible light.

Community – all the populations of different species living together and interacting with each other.

Confounding variables – any other variable, besides the independent variable, that also has an effect on the dependent variable.

Conservation – works to protect and preserve the Earth's ecosystems, so that future generations can live in a world that has the same biological richness we enjoy today.

Control – an experiment where the independent variable is either kept constant or removed.

Controlled variables – these variables are kept the same in an investigation.

Correlation – when one variable changes with another variable, so there is a relation between them. The strength of a correlation can be measured using a correlation coefficient. A correlation need not be a causal relation.

Data – recorded products of observations and measurements.

Death rate – the number of deaths in a population per 1000 people per year.

Decimal places – the number of digits, including zeros to the right of the decimal point.

Demographic transition model the change from high birth and death rates to low birth and death rates (expressed in rates per thousand).

Dependent variable – the variable that is being directly measured in an investigation.

Diversity index – a numerical measure of species diversity calculated by using both the number of species (species richness) and their relative abundance.

Dew point – the temperature at which relative humidity is 100%.

DNA – the genetic basis of life.

Dobson Unit (DU) – the unit of measure for total ozone.

Ecological footprint – 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 disposal of waste materials.

Ecologist – a scientist who studies ecology.

Ecology – the study of the interaction between organisms and their environment.

Ecosystem – the interaction between communities and their abiotic environment.

Edge effects – changes to abiotic conditions at the boundary where very different environments meet, and the corresponding effects on biotic factors (that is, the community).

Enhanced greenhouse effect increased warming of the Earth due to accelerated emissions of greenhouse gases due to human activities.

Environment – the external surroundings that act on an organism, population, or community and influence its survival and development.

Environmental value system (EVS) – a particular worldview that shapes the way an individual or group of people perceives and evaluates environmental issues, influenced by cultural, religious, economic and sociopolitical contexts.

Equilibrium – a state of balance among the components of a system.

Evaluated/Evaluation consideration of all the errors which may affect the accuracy of the results, identifying weakness and limitations in the method and explaining how such errors can be minimized or avoided.

Evaporation – moisture loss from the ground and from water surfaces.

Evenness – the proximity of the numbers of each species in a community. High evenness indicates all species are similar in abundance, and low evenness indicates that one or several species dominate an environment.

Evolution – inheritable changes in a population or species over many generations.

Explanation/explain – give a detailed account including reasons or causes.

***Ex situ* conservation** – the preservation of species outside their natural habitats, for example, in zoos and wildlife parks.

Fair test – a test in which only the independent variable has been allowed to significantly affect the dependent variable.

Flood hydrograph – a graph showing how discharge in a stream or river responds over a period of days to a storm event.

Flow – a movement of matter, energy or information between storages in a system.

Genetic diversity – the range of genetic material present in a population of a species.

Geographical information system (GIS) – a computer system that allows different types of geographical data to be linked to a location and displayed in an easily understandable form.

Germination – the initiation of growth by an embryonic plant in a seed or fruit, using stored nutrients.

Gleyed soil – a waterlogged soil.

GNI – gross national income; the sum of a nation's gross domestic product and the net income it receives from overseas.

Greenhouse effect – the natural process by which greenhouse gases, especially carbon dioxide, methane and water vapour, allow short-wave radiation to pass through the atmosphere, but trap a proportion of out-going long-wave radiation, thereby warming the Earth's atmosphere.

Gross primary productivity (GPP) – the total gain by producers in biomass made through photosynthesis, measured in a specific area in a specific period of time.

Gross secondary productivity (GSP) – the total gain by consumers in biomass through absorption. Gross secondary productivity is measured in a specific area in a specific period of time.

Habitat – the place where a species lives.

Habitat diversity – the range of different habitats in an ecosystem or biome. Conservation of habitat diversity usually leads to the conservation of species and genetic diversity.

Hazard – the potential to cause harm.

High pressure – atmospheric condition in which there is sinking air, relatively calm and dry conditions.

Horizon – an identifiable layer within a soil.

Human development index (HDI) – the level of development of a population, taking into account life expectancy, literacy levels and wealth (purchasing power parity (PPP)).

Humidity – a measure of the amount of moisture in the atmosphere.

Hypothesis (general) – a proposed explanation for limited data and observations from an experiment, the predictions of which may then be tested by investigation.

Hypothesis (statistical test) – there is a statistically significant difference between two variables.

Independent variable – the variable that is being changed in an investigation.

Indicator species – an organism used to assess a specific environmental condition.

Infiltration – water seeping into the ground.

Input – a flow entering a storage.

***In situ* conservation** – the conservation of species in their natural habitat.

Interception – the capture and storage of water by vegetation.

Interview – a method of data collection that consists of a series of pre-planned oral questions by the interviewer and oral responses by the research participant.

Investigation – a study consisting of a controlled experiment in the laboratory or field-based studies involving sampling.

Isohyet – a line on a map that joins areas of equal rainfall.

Keeling Curve – a line graph that shows seasonal and annual changes in atmospheric CO_2

Lichen – a symbiotic relationship formed by a fungus and an alga.

Limitations – the restrictions of a particular investigative technique or instrument. Limitations encountered during an investigation may influence the results.

Limiting factors – components of an ecosystem, either biotic or abiotic, that limit the distribution or numbers of a population.

Line of best fit – a line drawn to pass through as many points as possible, so that most lie on the line or roughly evenly spaced on either side of the line.

Loam soil – a mixed soil consisting of sand, silt and clay.

Low pressure – atmospheric conditions consisting of rising air, characterized by windy and wet conditions.

Measuring/measure – obtain a value for a physical quantity.

Measurement – the act or process of recording a physical quantity (amount) and assigning the derived value to the relevant SI unit.

Melanism – development of a dark-coloured pigment, melanin, in the outer surface of an organism.

Methodology – the methods/techniques used to carry out an investigation and their justification.

Microclimate – a small-scale climate such as in an urban area or a forest.

Model – a simplified version of a system. It shows the flows and storages as well as the structure and workings.

Motile – an organism that can actively move from place to place.

Natural change – birth rate minus death rate (expressed as a percentage).

Natural decrease – when death rates are higher than birth rates (expressed as a percentage).

Natural increase – when birth rates are higher than death rates (expressed as a percentage).

Net primary productivity (NPP) – the gain by producers in biomass once energy from respiration has been removed, measured in a specific area in a specific period of time.

Net secondary productivity (NSP) – the gain by consumers in biomass once energy from respiration has been removed. Net secondary productivity is measured in a specific area in a specific period of time.

Niche – a complete description of a species' ecology, that is, where, when and how it lives.

Non-motile – an organism that cannot move or, for the purposes of sampling, can only move very slowly (such as limpets on a rocky shore).

Null hypothesis – there is no statistically significant difference between two variables.

Organic content – carbon-containing content.

Output – a flow leaving a storage.

Ozone hole – the thinning of the concentration of ozone in the stratosphere.

Percentage cover – the proportion of a quadrat covered by a species, measured as a percentage.

Percentage frequency – the percentage of quadrats in an area in which at least one individual of the species is found.

Photosynthesis – the production of carbohydrates in chloroplasts of cells, from water and carbon dioxide, using light energy.

Podzol – a type of soil formed under very acidic conditions, and therefore with no earthworm activity, with very distinct soil horizons.

Population – a group of individuals of the same species.

Population density – the number of individuals of each species per unit area.

Population ecology – concerned with the study of factors that influence the numbers and structure of a population.

Precision – describes the reproducibility of repeated measurements of the same quantity and how close they are to each other.

Prediction – the change in the dependent variable due to a causal change in the independent variable.

Primary data – the actual data measured and may include associated qualitative data (observations).

Processed data – data that are ready for analysis.

Processed variable – a variable that can be produced by transforming a measured variable through mathematical manipulation.

Purchasing power parity (PPP) local levels of income related to local prices.

Quadrat – a square frame which outlines a known area for the purpose of sampling.

Qualitative data – observations not involving measurements, such as those recorded in an ecological study to note conditions in a survey area.

Quantitative data – numerical data.

Questionnaire – a document that asks the same questions of all individuals in a sample.

Rainfall – precipitation falling as a liquid. Precipitation includes all forms of moisture including rain, snow, dew and fog.

Random sampling – a method of choosing a sample from a population without any bias.

Range – the range of values covered by the independent (or dependent) variable. The difference between the smallest and largest values.

Raw data – these are the data collected without any processing.

Relative abundance – the relative number or amount of one species compared to the other species in a community.

Relative humidity – a measure of the amount of water vapour in the air compared to the maximum that could be contained by the air at the same temperature when the air is saturated.

Rendzina – a type of soil found on chalk or limestone, consisting of organic-rich material on top of bedrock.

Replicate – a repeating of the entire experiment run at the same time.

Respiration – the controlled release of energy in cells from organic compounds, to produce ATP.

Risk – the probability of harm occuring.

Risk assessment – a consideration of the hazards that impact human health that could be encountered during an investigation as well as the environmental impact of disposal.

Sample – a subset of a whole population or habitat used to estimate the values that might have been obtained if every individual or response was measured.

Sample size – the number of samples taken from a population.

Scientific method – the use of controlled observations and measurements during an experiment to test a hypothesis.

Secondary data – data obtained from the literature.

Sensitivity – the number of significant digits to which a quantity can be reliably measured.

Significant figures – the digits of a number that are used to express it to the required degree of accuracy, starting from the first non-zero digit.

Simulation – a representation of a process or a system which imitates a real or an idealized situation.

Soil – a mix of mineral particles and organic matter that covers the land and in which most plants grow.

Soil horizons – the horizontal layers within a soil distinguished by the colour, chemical composition, permeability and texture.

Soil profile – a vertical section through a soil, from the surface down to the parent material (bedrock), which shows the soil layers or horizons.

Soil texture – the size of particles in a soil, notably sand, silt and clay.

Species – a group of organisms that can potentially interbreed to produce fertile offspring.

Species diversity – the variety of species per unit area. This includes both the number of species present and their relative abundance.

Species richness – the number of species in a community.

Spectrophotometer – an instrument for measuring the absorbance of a solution using ultraviolet radiation or visible light.

Standard deviation – the spread of a set of data from the mean of the sample is a measure of the variability of a population from a sample.

Standard error – an estimate of the reliability of the mean of a population sample. A small standard error indicates that the mean value is close to the actual mean of the population.

Statistical significance – a calculated value that is used to establish the probability that an observed trend or difference represents a true difference that is not due to chance alone.

Stemflow – moisture that flows down the stem of a plant.

Storage – The locations where matter, energy or information is held in a system.

Storm or flood hydrograph – the variation in discharge in a stream or river following one or more flood events.

Strategy – a plan of action to achieve specific goals.

Succession – the process of change over time in a biological community.

Sustainability – the use of global resources at a rate that allows natural regeneration and minimizes damage to the environment.

System – a set of interrelated parts and the relationships between them, which together constitute an entity or whole.

Tipping point – a critical threshold when even a small change can have dramatic effects and cause a disproportionately large response in the overall system.

Transect – arbitrary line through a habitat, selected to sample the community.

Transfers – processes that involve a change in location within the system but no change in state.

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

Treatments – well-defined conditions applied to the sample units.

Trend – the general relationship shown by a set of related measurements.

Trent biotic index – the use of freshwater species to make conclusions about the level of pollution.

Turbidity – a measure of the amount of suspended sediment in a body of water, leading to discolouration and a 'murky' appearance.

Validity – a measure of the confidence in a conclusion. It depends on the range and reliability of observations and measurements. Statistical tests may be used to assess the reliability of data.

Validity (of methodology) suitability of the investigative methodology to answer the research question.

Variable – a factor that is being changed, measured, or kept the same in an investigation.

Weather – the state of the atmosphere at any given time, generally less than one week. Weather includes temperature, precipitation type and amount, relative humidity, air pressure, wind speed and direction, and cloud cover.

Zero error – zero error is how far away from zero that a reading of an instrument is, when the real value is known to be zero. It can be either positive or negative.

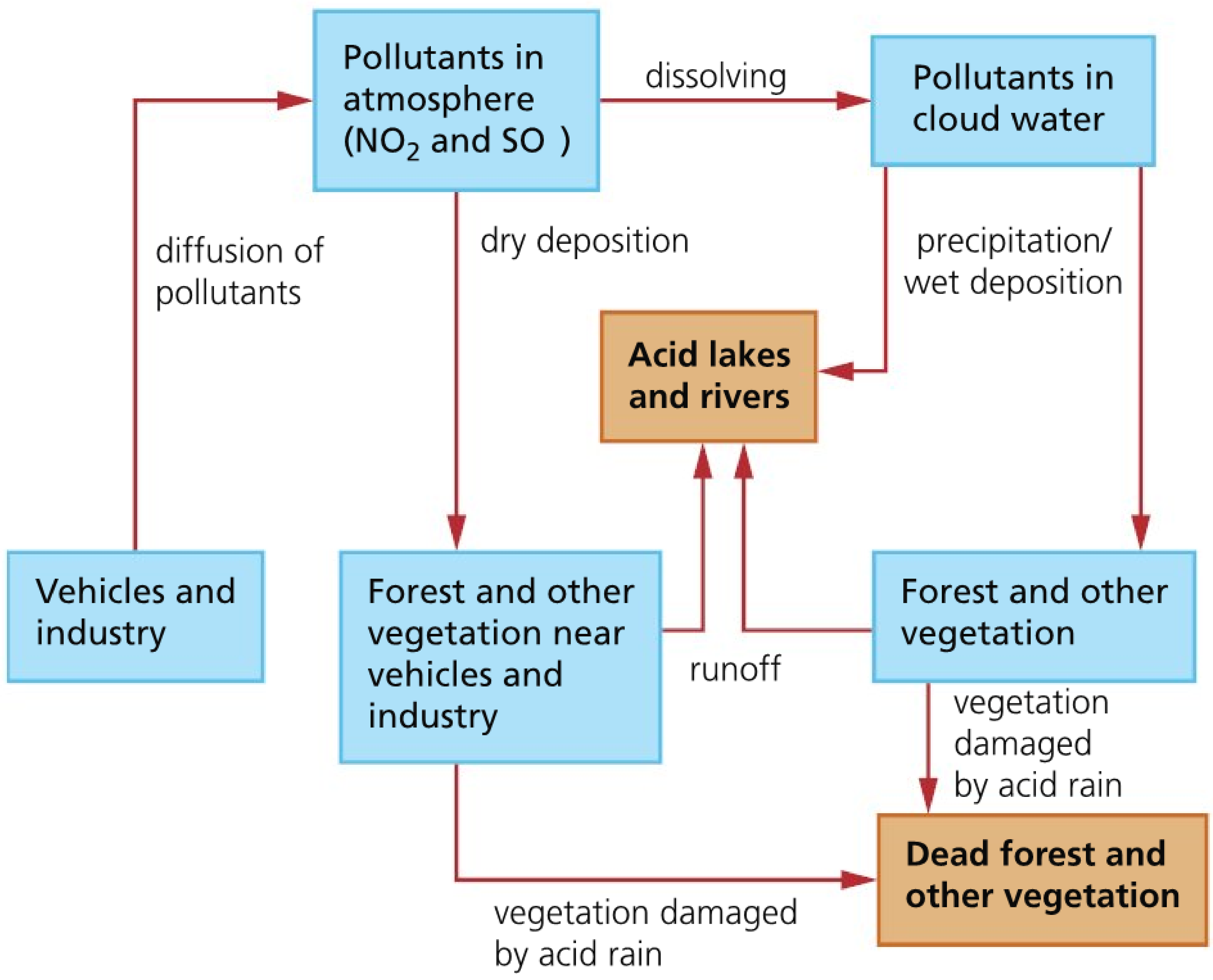
Zonation – the arrangement or patterning of plant communities or ecosystems into parallel or sub-parallel bands in response to change, over a distance, in some environmental factor.

Answers

Chapter 1

Page 8

1



A system diagram to show cause of acid rain and its effects

2

Transfers	Transformations
Feeding on plant material by herbivores	Photosynthesis (CO_2 into glucose)
Feeding on herbivores by carnivores	Respiration (organic matter into CO
Feeding on dead organisms by decomposers	Combustion (organic matter into CO_2)
CO_2 from atmosphere dissolving in rainwater	Incomplete decomposition and fossilization
CO_2 from atmosphere dissolving in oceans	

Page 13

3 1.002×10 , 5.4×10 , 6.9263×10^9, -3.93×10^2, 3.61×10^{-3} and -3.8×10^{-3}

4 1930, 30.52, –429, 6,261,000,000 and 0.00000009513

5 a Nanogram, ng
  b Microsecond, µs
  c Millimetre, mm

6 a 10^{-12} second
  b 4.0 km
  c 4.56×10^{-3} g

Page 14

7 The number 14.44 has four significant figures – all non-zero digits are significant. The number 9000: since there is no decimal point, the zeros may or may not be significant. When considering numbers with zeroes at the end we must state the number of significant figures. The number 3000.0 has five significant figures – the decimal point implies that we have measured to the

nearest 0.1. The number 1.046 has four significant figures – zeros between digits are significant. The number 0.026 has two significant figures – zeros to the left of the decimal point only fix the position of the decimal point. They are not significant. The rules are the same when dealing with numbers expressed in standard form, so 6×10^{23} has one significant figure, 6.02×10^{23} has three significant figures.

Page 15

8 654.389 becomes 654 because the first non-significant digit is 3. 65.4389 becomes 65.4. 654,389 becomes 654,000 because we need to put the zeros in to hold the place values. 56.7688 becomes 56.8 because the first non-significant digit is 6. 0.03542210 becomes 0.0354. Note that three significant figures is not the same as three decimal places, which would give 0.035.

Page 18

9 A field sketch is a hand-drawn summary of an environment that you are looking at.

10 Figure 3.21 on page 197 of the *Environmental Systems and Societies 2nd Edition* textbook (Davis and Nagle, 2015, Pearson) is a good example of a sketch map. It has a scale, orientation and shows clearly the regional and national location of the Danum Valley.

Page 21

11 Question 1 is a closed question, question 3 is a scale question and question 5 is an open question.

12 The questionnaire could be improved by having a more logical structure (for example, the causes and potential solution to poor air quality) and by having more closed questions.

13 A sample of 30 would be preferable to ensure statistical validity (30 is considered the minimum size for a large sample).

14 A town centre would be a good place to undertake the questionnaire, as there are large numbers of people present, representing a variety of ages, gender and most likely socio-economic groups. It would not take too long to collect the data from 30 people in a town centre compared with a residential area.

15 Random sampling would give every individual an equal chance of being interviewed/questioned whereas stratified sampling would ensure that a representative sample from different groups (gender, ages, socio-economic groups) are included in the questionnaire.

Page 22

16 All the questions are open questions.

17 The questionnaire is biased towards asking for negative responses. There is little scope to make positive comments about the new development.

18 The results would be hard to analyse as the questions are open questions – there may be a large number of responses that are one of a kind.

19 An appropriate strategy might be to have a stratified sample so that people of different ages, and needs, can have their say. The questionnaire should be given to both genders, people of all ages and people of different socio-economic backgrounds.

Chapter 2

Page 28

1

Abiotic factor	How is it measured?	Evaluation
Wind speed*	Anemometer	Gusty conditions can lead to large variations in data
Temperature[+]	Thermometer	Problems in data reproducibility and accuracy if temperature not taken from consistent depth
Light[+]	Light meter	Cloud cover changes light intensity, as does shading from plants or light meter operator
Soil compaction*	Penetrometer	Readings must be taken in the same way, with the metal bolt (Figure 2.4) dropped from the same height
Flow velocity[x]	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 oxygen concentration (in ppm)[x]	Dissolved oxygen meter	Possible contamination from air/oxygen bubbles in the samples when using dissolved oxygen meter
Soil moisture*	Evaporate water; soil moisture probes	If soil is too hot when evaporating water, organic content can also burn off

The measurement of abiotic factors in ecosystems. Type of ecosystem where technique is mainly used: *terrestrial; [x]freshwater; marine; all three

Page 30

2 Used to determine population size of animals in large areas; there must be an adequate time interval between capture and recapture of animals; the marking method must not decrease chances of survival of the organisms/must not harm the animals/must not introduce bias when recapturing animals; population size can be calculated when there is enough/relevant data; population size is calculated by multiplying number of animals captured (marked and released) on first day by the number of animals captured on second day, divided by the number of marked animals recaptured on second day; examples include snails/dragonflies/small mammals such as mice/*other suitable examples*.

Page 36

3 For example: wind speed – gusty conditions can lead to large variations in data; temperature – problems in data if temperature not taken from consistent depth; light – cloud cover changes light intensity, as does shading from plants or light meter operator.

4 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.

5 A sample population needs to be captured, marked, released and recaptured. The formula for the Lincoln index is:

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

where N = total population size of animals in the study site; n_1 = number of animals captured and marked on first day; n = number of animals captured on second day; m = number of marked animals recaptured on second day.

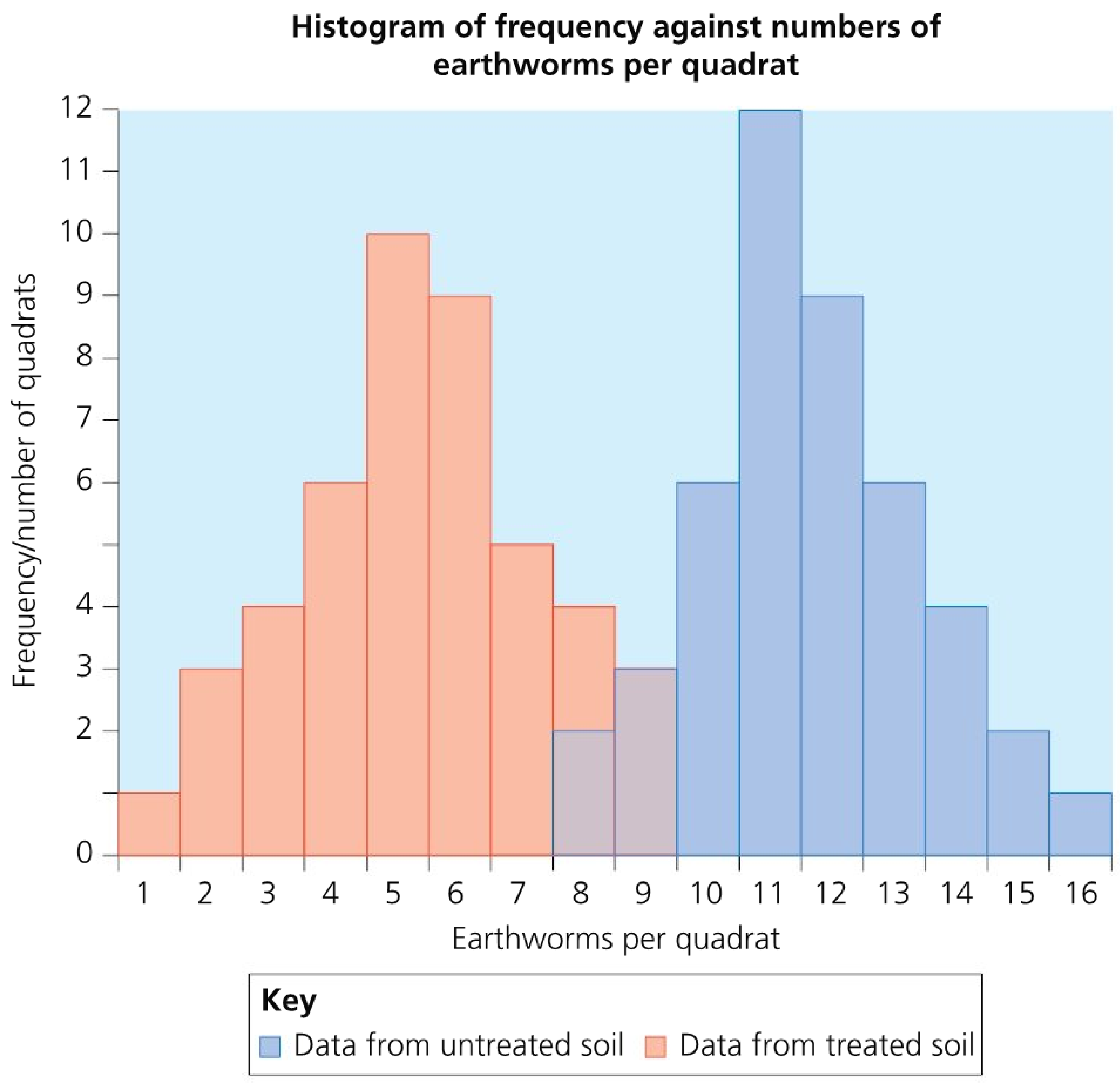
6 All biomass from sample area (for example, 1 m^2) is removed; with plant material, roots are dug up and removed as well as above-ground biomass; the sample is weighed in a container of known weight; the sample is put in a hot oven (80 °C); after a specific length of time the sample is reweighed; the

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.

Page 42

7 Transects are used to measure changes along the gradient; this ensures that all parts of the gradient are measured; quadrats can be used to sample at regular intervals along a transect; quadrats are used for estimating the abundance of plants and non-motile animals; a quadrat is sampling area enclosed within a frame whereas a transect is a line through a habitat or environmental gradient selected to sample the community.

8 a



An investigation of the effect on earthworm populations of pesticide treatment

b Untreated soil has a higher abundance of earthworms than soil treated with pesticides; pesticides have reduced the abundance of earthworms; pesticides are non-specific and have affected earthworm populations as well as target pest species; pesticides may decrease the reproductive potential of earthworms/decrease metabolic processes/decrease enzymatic activities/increase individual mortality/decrease growth/change feeding behaviour.

Page 42

9 Ecological gradients are found where two ecosystems meet (for example, on beaches or on lake shores) or where an ecosystem suddenly ends (for example, at forest edges). Both biotic and abiotic factors vary with distance and form gradients.

10 Transects are used to measure changes along the gradient, which ensures all parts of the gradient are measured; abiotic factors would be measured at regular intervals (for example, every 5 m) using a standard method.

11 Frame quadrats, which are empty frames of known area (for example, 1 m);grid quadrats, which are frames divided into 100 small squares; point quadrats, which are made from a frame with 10 holes, inserted into the ground by a leg.

12 A cross staff is used to move a set distance (for example, 0.6 m) vertically up a transect. The staff is set vertically and a point measured horizontally from an eyesight 0.6 m from the base of the staff; biotic and abiotic factors are measured at each height interval.

Chapter 3

Page 46

1 For habitat B, Simpson's index:

$$= \frac{100(99)}{50(49) + 30(29) + 15(14) + 5(4)}$$

$$\frac{9900}{2550}$$

$$= 2.79$$

2 Habitat A has the greatest diversity and habitat E the lowest; habitat A has the greatest evenness between species, with habitat E dominated by one species (that is, lowest evenness); species diversity is a combination of the number of species and their relative abundance; higher diversity indices are recorded when all species are equally abundant, indicating a large range of available niches, whereas low species diversity indicates a lower number of niches.

3 Habitat A is more complex with a greater array of niches than habitat E; habitat A may be more ancient than habitat E; other habitats lie between the extremes demonstrated by habitats A and E.

Page 52

4 You will need to discuss your ideas with a conservationist in your country and area. Are there national or local reserves or conservation areas, with voluntary or professional management who can give you guidance? Points to consider: are there threats from invasive/non-native species? Is the area protected under law or under voluntary arrangements? Does the shape of the reserve help conserve species? Is the area fragmented with significant edge effects? Is there evidence that species within the reserve have been and are being protected?

Chapter 4

Page 55

1 a The rainfall under coniferous woodland varies between 1.0 and 2.0 mm whereas that under deciduous vegetation varies between 13.0 and 16.0 mm. The rainfall under deciduous vegetation has a higher total and range. In contrast, on the flat roof (no vegetation, that is, a control plot) the rainfall varies between 16.5 and 18.5 mm. Finally, under the evergreen bushes, rainfall varies between 7.0 and 9.0 mm. The reason for these differences is due to interception. Deciduous trees shed their leaves in winter, and there is less interception over winter compared with summer. In contrast, coniferous trees have a year-round vegetation cover, and continue to intercept rainfall in winter, thereby reducing the amount reaching the rain gauges. The exposed flat roof has no vegetation, and so no interception, and therefore high levels of rain reaching the gauges.

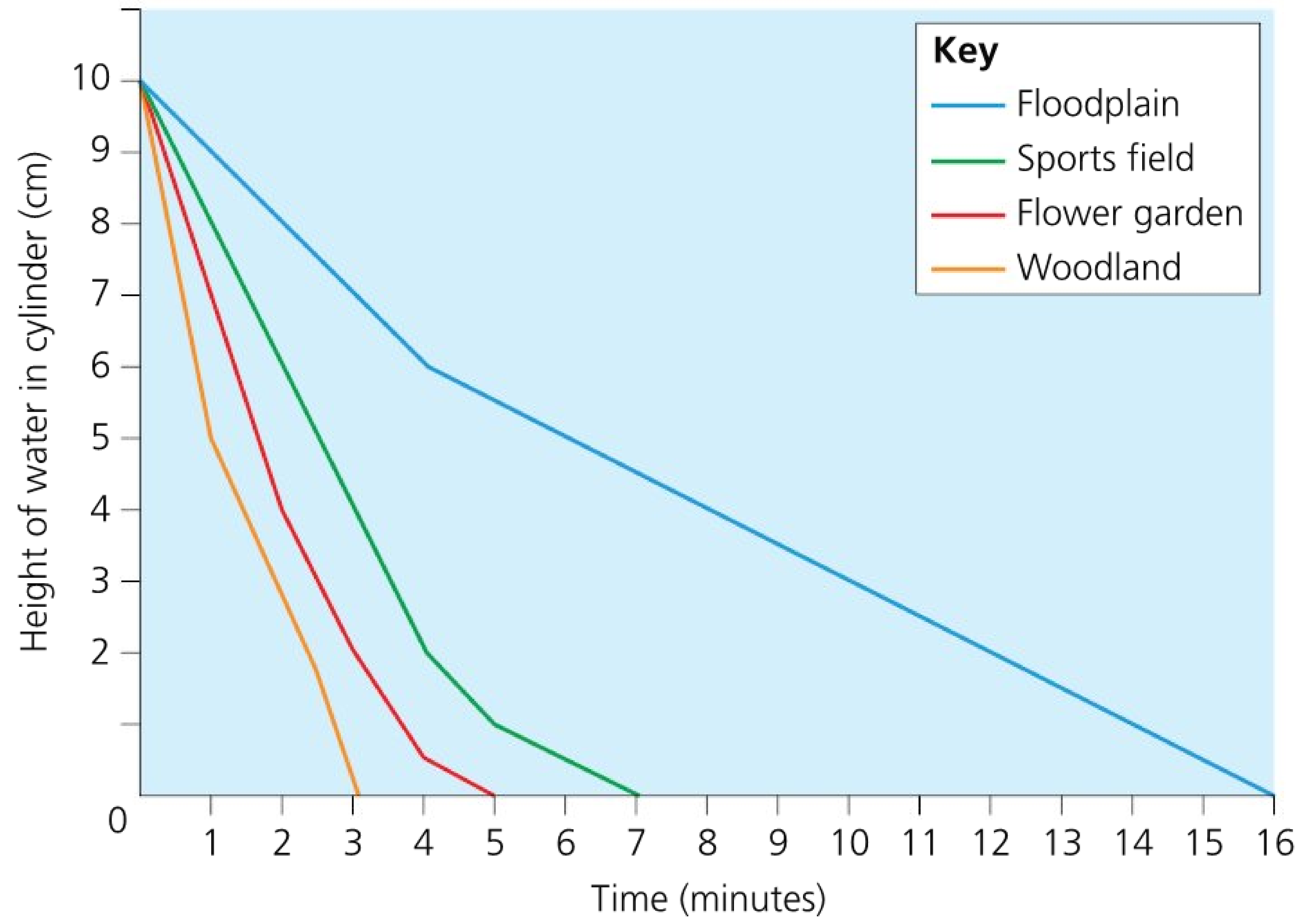
b The survey was likely to have taken place in winter, as deciduous trees would have lost their leaves and interception would have been reduced.

c In summer, there would be increased interception under deciduous trees, because they are in leaf.

d The new plantation will have smaller trees (which will not grow to a large size for many years), covering a small area. Hence, interception will be low, and the amount of rain reaching the ground will be high (but declining over time as the trees grow in size).

Page 56

2 a



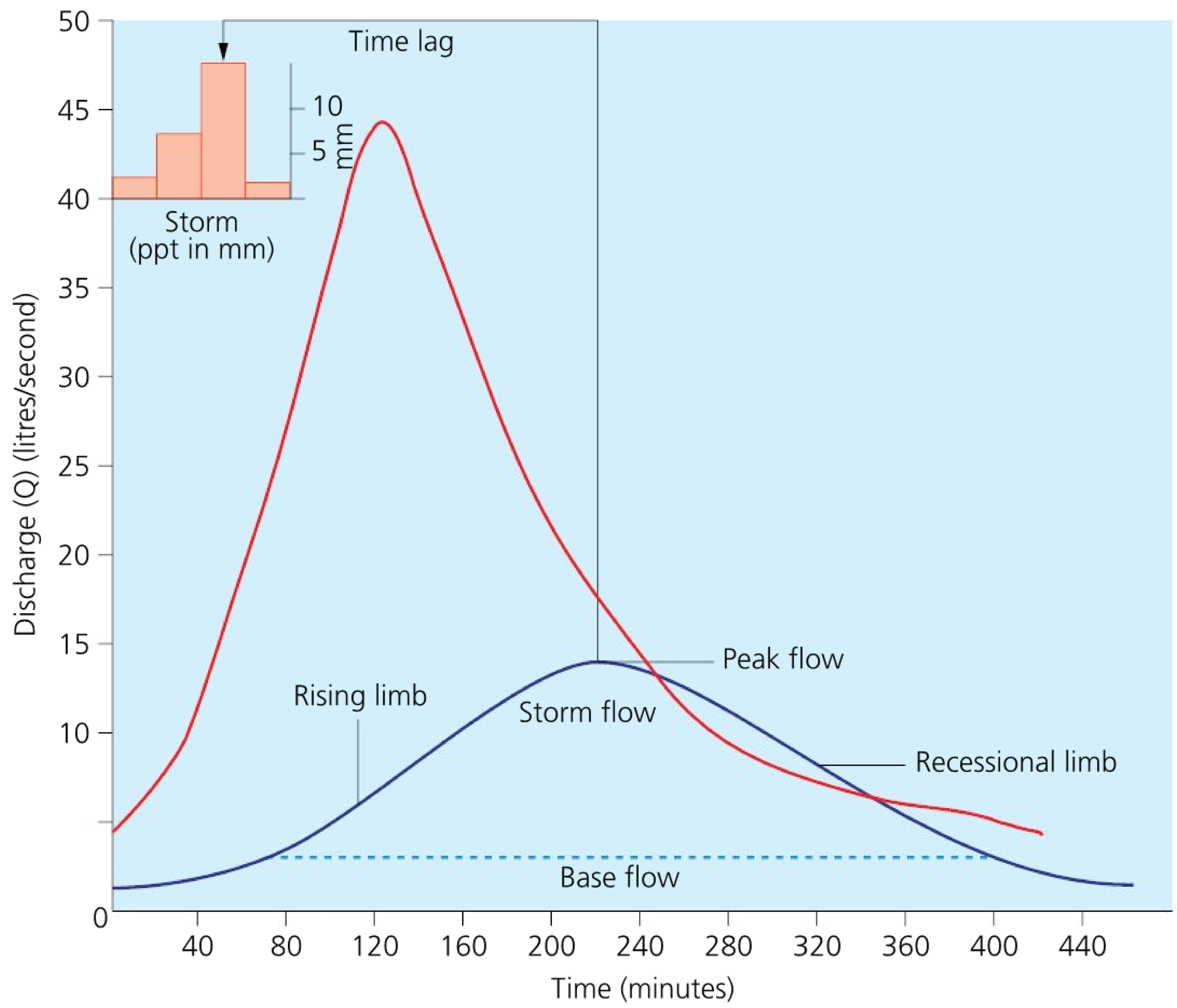
Infiltration rates under different vegetation types

b The woodland has the fastest rate of infiltration, followed closely by the rose garden and the sports field. The flood plain has the slowest rate of infiltration. The water takes just three minutes to drain away in the woodland compared with 16 minutes on the floodplain.

c The woodland intercepts rainfall and some of it drips onto the forest floor, or flows down the stem, delivering rain at a steady rate, enabling it to seep into the ground. In contrast, the floodplain has less interception, so the water may form puddles on the surface. In addition, floodplains are normally formed of clay or alluvium, fine-grained sediments which slow down the rate of infiltration. In contrast, under the woodland the soil is likely to consist of more free-draining materials, including soil organic matter, litter, and humus.

Page 57

3 a



A flood event and a storm hydrograph

b Peak flow is higher in the urban hydrograph (44 l s^{-1}) compared with the rural hydrograph (14 l s^{-1}) and the time lag is shorter, 120 minutes compared with 220 minutes for the rural hydrograph.

c Both the rising limb and the recessional limb are higher in the urban hydrograph than in the rural one.

d The reasons for these differences are the increase in the amount of impermeable surfaces in urban areas that is, the increase in concrete, tarmac and other building materials, as well as the increase in the drainage density of the area (the increase in the number and length of drainage channels, gutters, sewers and drains) in urban areas relative to rural areas. This means that less water can infiltrate into the ground and the dense network of artificial channels delivers it to the river quickly.

Pages 61–62

4 a Simpson's diversity index Site 1: 1.51, Site 2: 6.12.

b Trent biotic index Site 1: 2, Site 2: 7.

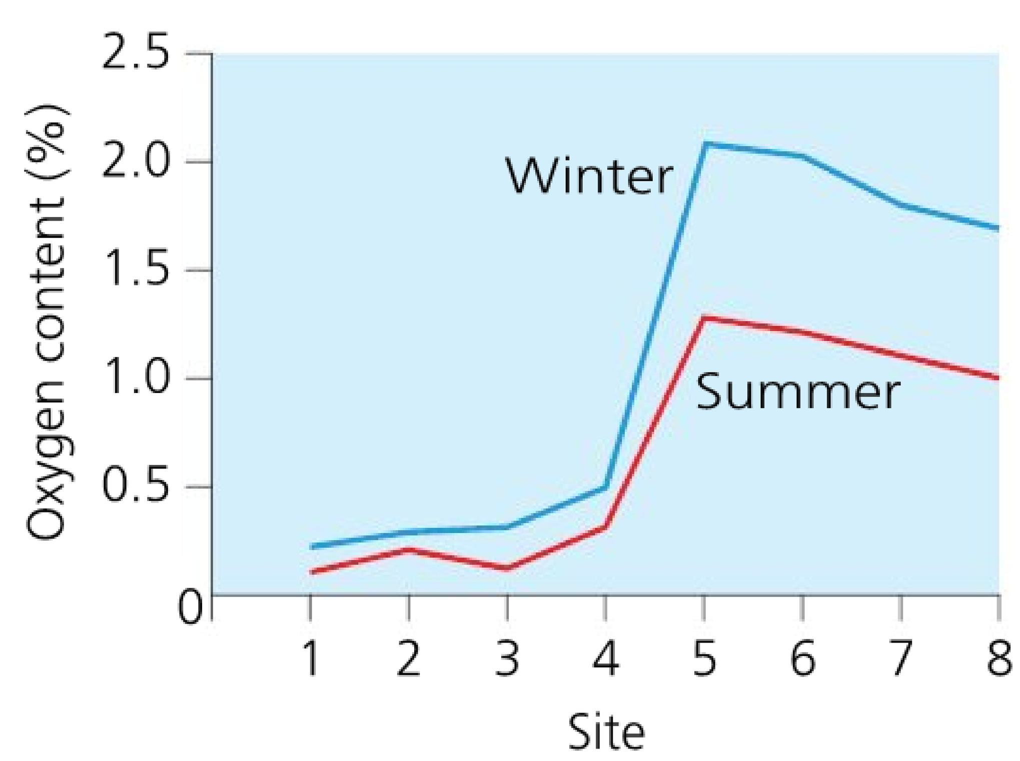
5

Site	Discharge $m^3 s$ (summer)	Discharge $m^3 s^{-1}$ (winter)
1	0.42	0.78
2	0.46	1.12
3	0.66	1.12
4	1.14	1.80
5	2.34	4.05
6	3.28	4.60
7	2.73	4.05
8	2.80	4.32

a i Discharge varies between winter and summer. Discharge in summer is lower for example, rising from 0.42 $m^3 s^{-1}$ at site 1 to 2.84 $m^3 s^{-1}$ at site 8. In winter, discharge varies from 0.78 m s^{-1} at site 1 to 4.32 $m^3 s^{-1}$ at site 8.

ii The reasons for this may include higher rainfall in winter, lower temperatures in winter (so less evaporation) and fewer deciduous trees in leaf in winter, so there is less interception.

b



Oxygen levels above and below the sewage outlet and weir

Oxygen content increases rapidly between sites 4 and 5 from 0.3% to 1.8% in summer, and from 0.5% to 2.1% in winter.

The reasons for the change are likely to be the presence of the weir between sites 4 and 5. This causes the water to 'tumble' over the weir, and in so doing, it incorporates oxygen from the air into the water.

c In the summer, the stream is relatively warm with a temperature of 18–17 °C above the sewage outlet and 20–23 °C below the sewage outlet. In contrast, in winter, the water is colder that is, 12–13 °C above the sewage outlet, and 15–17 °C below the outlet. It appears that water joining the stream from the sewage outlet raises the temperature of the stream.

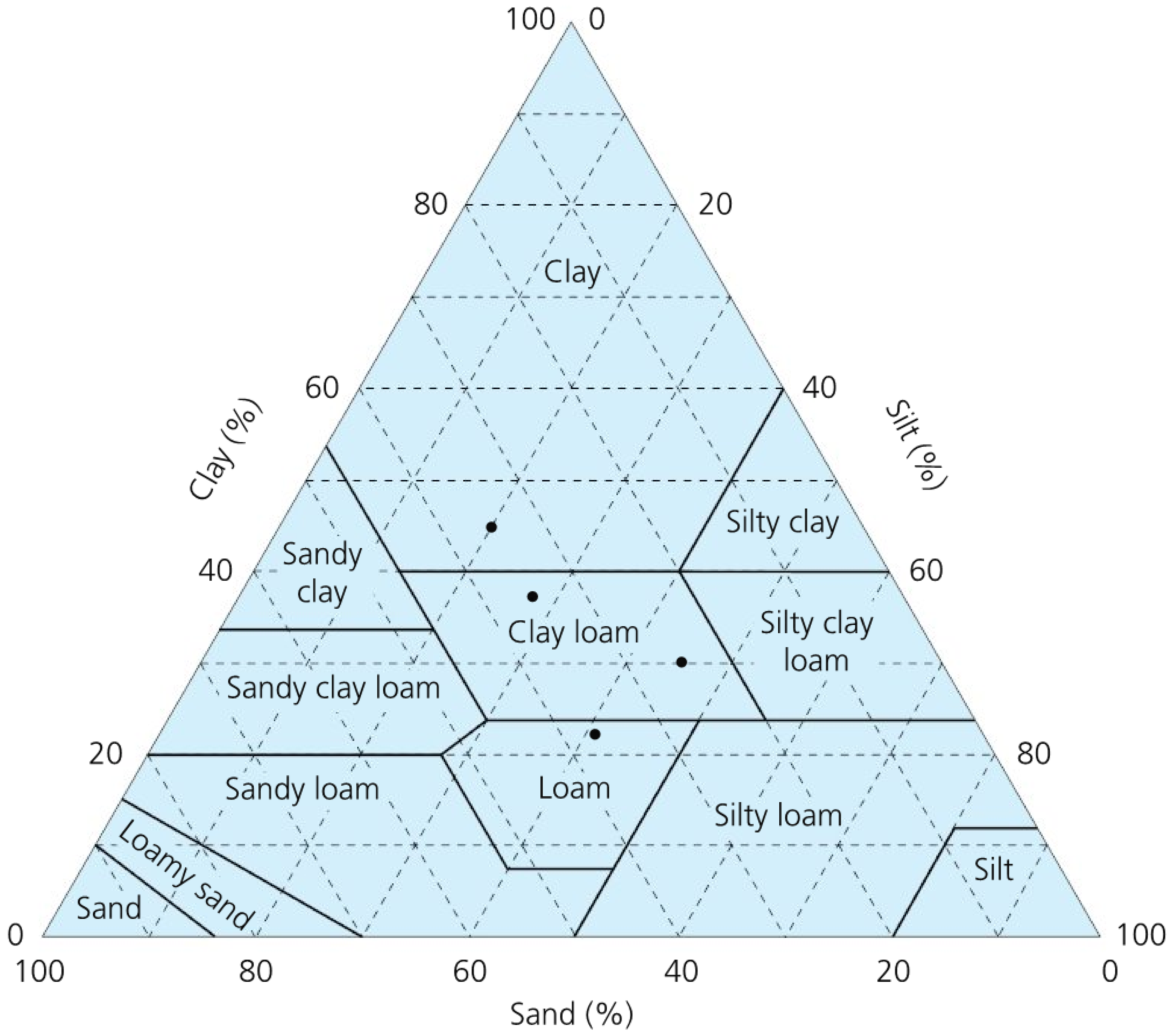
Chapter 5

Page 69

1 a

Soil	Sand (%)	Silt (%)	Clay (%)
A	10	70	20
B	10	30	60
C	50	30	20
D	70	20	10

b



Triangular graph showing soil composition

c i Clay loam
ii Clay
iii Loam
iv Clay loam

Page 72

2 a The temperature for the sand soil is the highest. It ranges from a low of about 13 °C at 5 a.m. to over 50 °C at noon, and then decreases rapidly. Loam soils have a similar pattern but have a peak temperature of about 45 °C. The coolest soils are peat and clay. Clay temperature peaks at around 35 °C and peat about 38 °C. However, by night peat and clay do not get as cold (15–16 °C) compared with sand and loam (around 14 °C).

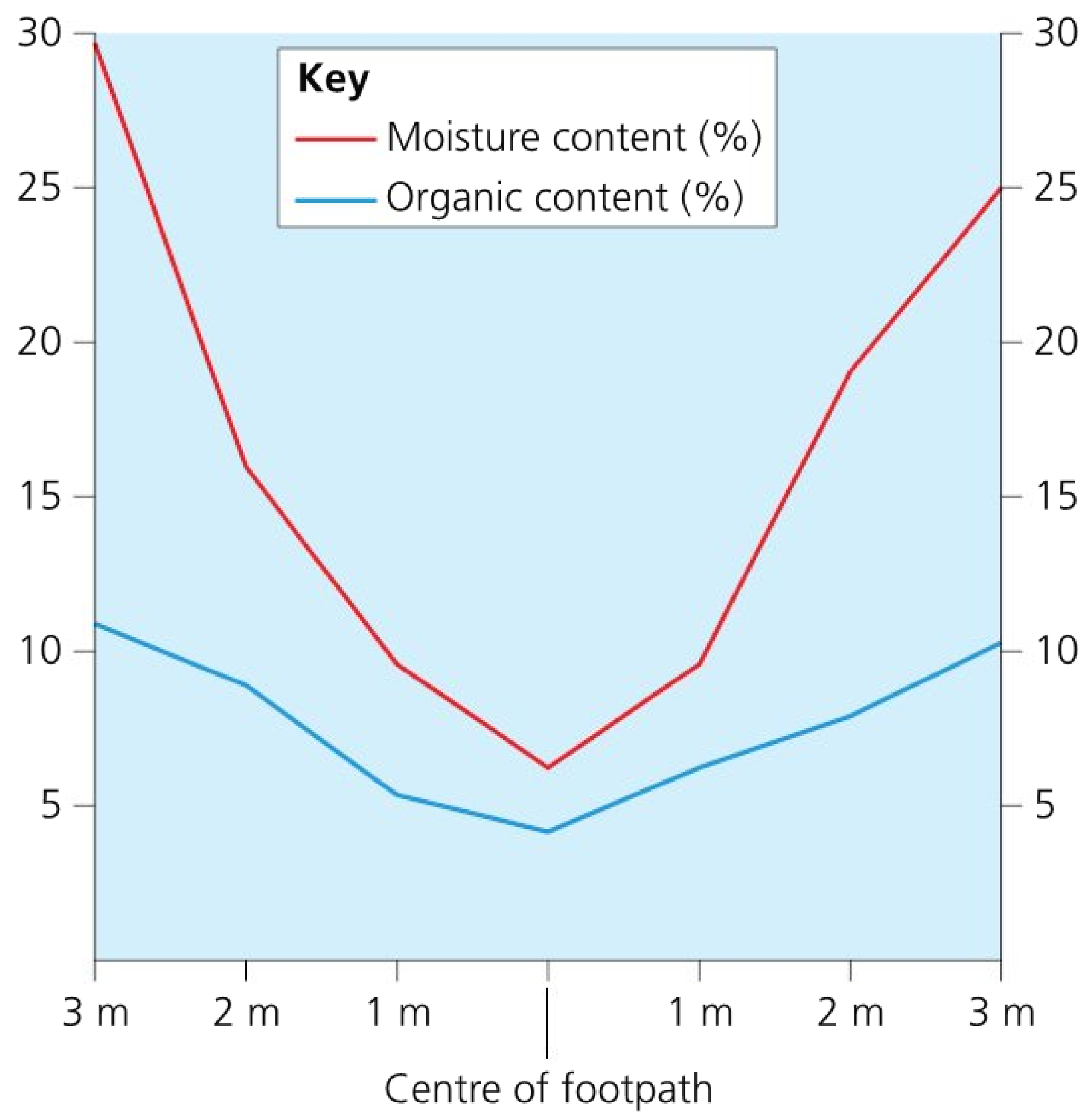
b One implication for farmers is that plant germination and growth may be more rapid in sand and loam, although the sand soil may in fact be too hot for many plants. In addition, sand soils may contain limited amounts of moisture so some plants may experience water stress. Clay soils, although colder, are still warm, and, combined with more moisture, may provide a good medium for growth in these circumstances.

c The top of the bare soil is warmer than under the grass. The temperature is 5.2 °C warmer in the bare soil compared with that under grass at 10.00 hours, rising to a maximum difference of 9.9 °C at 14.00 hours.

d In winter, the temperature differences are likely to be less marked, as there is less insolation received and, away from the equator, shorter day lengths. In fact, in some areas, temperature in soils under vegetation may be warmer than under bare soil, especially if the bare soil is located in high latitudes or high altitudes.

Page 75

3 a



Line graphs showing moisture content and organic content across a footpath

b With increased distance from the centre of the footpath, there is increasing moisture content. For example, at the centre of the footpath moisture content is 7.3% and organic content 3.8%. However, by 1 metre away the moisture content has risen to between 9.1% and 10.3%, and organic content has risen to between 5.2% and 6.2%. By 3 metres from the centre of the path, the moisture content has risen to 25.6%–29.4%, and the organic content has risen to 10.5%–10.6%.

c In the English Lake District National Park (UK), it costs up to £250 000 to repair one mile of eroded footpath (£160/metre). Helicopter costs (needed to transport building stone to remote upland areas) have doubled over the last ten years. The Lake District attracts some 15 million visitors per year.

Footpath erosion can have many unexpected impacts. For example, fish species, such as trout and salmon, are under threat because their spawning grounds are damaged by soil washed off the paths and into streams and lakes.

Helicopters cost approximately £1 200 an hour to carry heavy stones to remote parts. Some 500 trips are made each year.

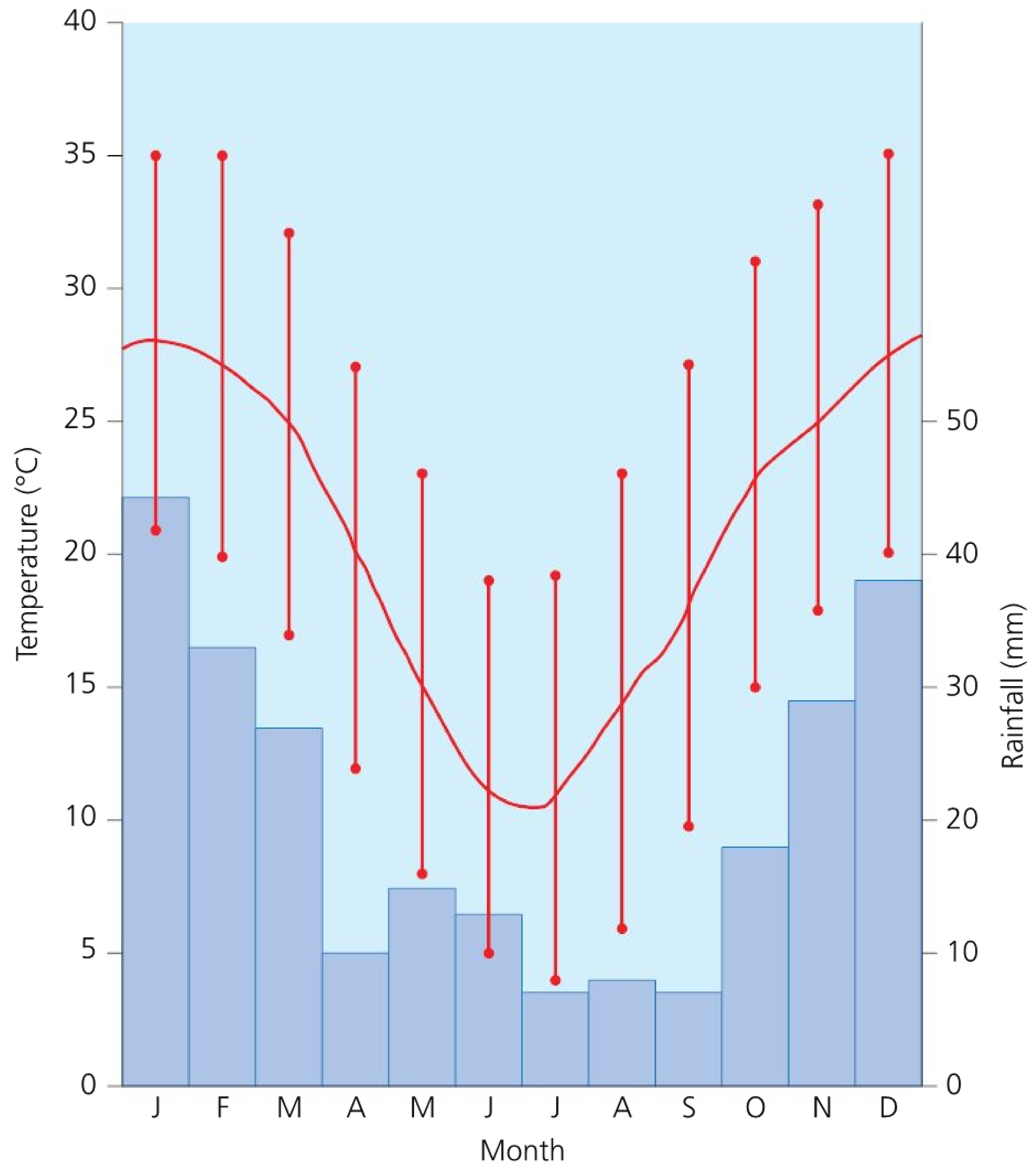
Footpath erosion has led to accelerated peat loss, as paths become degraded and wider. The creation of gullies (narrow, steep channels) in peat causes erosion of the moors and leads to the drying out of the moors.

This can cause accelerated peat decomposition; pollution of local water courses due to dissolved organic carbon in the water; reduced water tables and habitat loss. Footpath erosion makes paths unsafe as well as unsightly.

Chapter 6

Page 79

1 a



Climate graph for Alice Springs, Australia

b i The mean temperature has a maximum value around December–February (27–28 °C) and a minimum value in June and July (12 °C).

ii Rainfall in Alice Springs is higher in December and January (82 mm in those two months) whereas only 22 mm falls between July and September.

c The maximum range of temperature is 17 °C in August and September.

d The climate can have a number of potential impacts. The area is a desert (less than 250 mm of rainfall) so water shortages will be a problem, especially between April and October. This will have an impact on agriculture and food production.

Page 80

2 a The clouds are mainly located along the eastern coast of the country in this high-pressure map.

b Maximum temperature is 28 °C, minimum temperature 16 °C.

3 a The potential problems in summer are mainly related to poor air quality, drought and heatstroke.

b In winter, the problems include frost, freezing conditions, fog and freezing fog.

Page 86

4 a Humidity is the amount of moisture in the air. Absolute humidity is the actual amount of moisture held by a cubic metre of air and is expressed in $g\,m^{-3}$. By contrast, the relative humidity expresses this amount of air relative to the largest amount air at a given temperature can carry.

b Cold air can hold less moisture than warm air, so as the temperature falls, if there is no change in the amount of moisture in the air, the relative humidity increases. Similarly, if there is no change in the amount of moisture present, as air temperature rises, the relative humidity decreases as the air could hold more moisture.

Page 88

5 a A Stevenson screen is a wooden box standing on four legs at a height of about 120 cm. The screen is built so that the shade temperature of the air can be measured. The sides of the box are slatted to allow free entry of air, and the roof is made of double boarding to prevent the solar energy from reaching the inside of the screen. Insulation is further improved by painting the outside of the screen white so as to reflect much of the solar energy. The screen is usually placed on a grass-covered surface, thereby reducing the radiation of heat from the ground.

b A Six's thermometer measures maximum and minimum temperatures.

c The weather readings are taken at the same time each day to ensure that all recordings are for a 24-hour period.

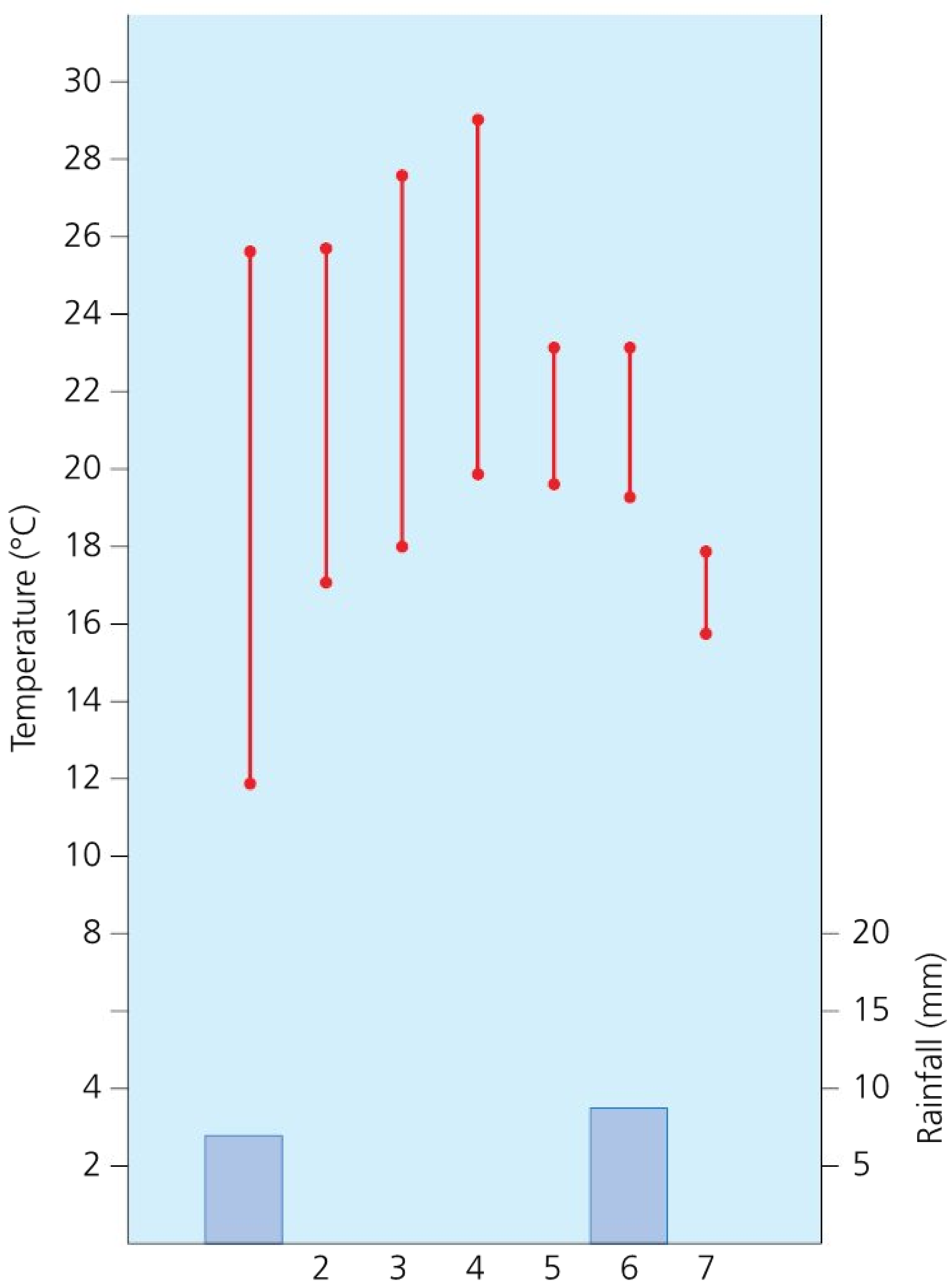
d A rain gauge is placed in an open space so that only raindrops enter the funnel of the gauge, and no run-off from trees, buildings or other objects can get into the funnel. The gauge is sunk into the ground so that the top of the funnel is about 30 cm above ground level. This is to prevent the solar energy from evaporating any water collected and to ensure no rain splashes up from the ground into the funnel.

e A wind vane is used to record wind direction. It consists of a horizontal rotating arm pivoted on a vertical shaft. The rotating arm has a tail at one end and a pointer at the other. When the wind blows, the arm swings until the pointer faces the wind. The directions north, east, south and west are marked on the arms which are rigidly fixed to the shaft.

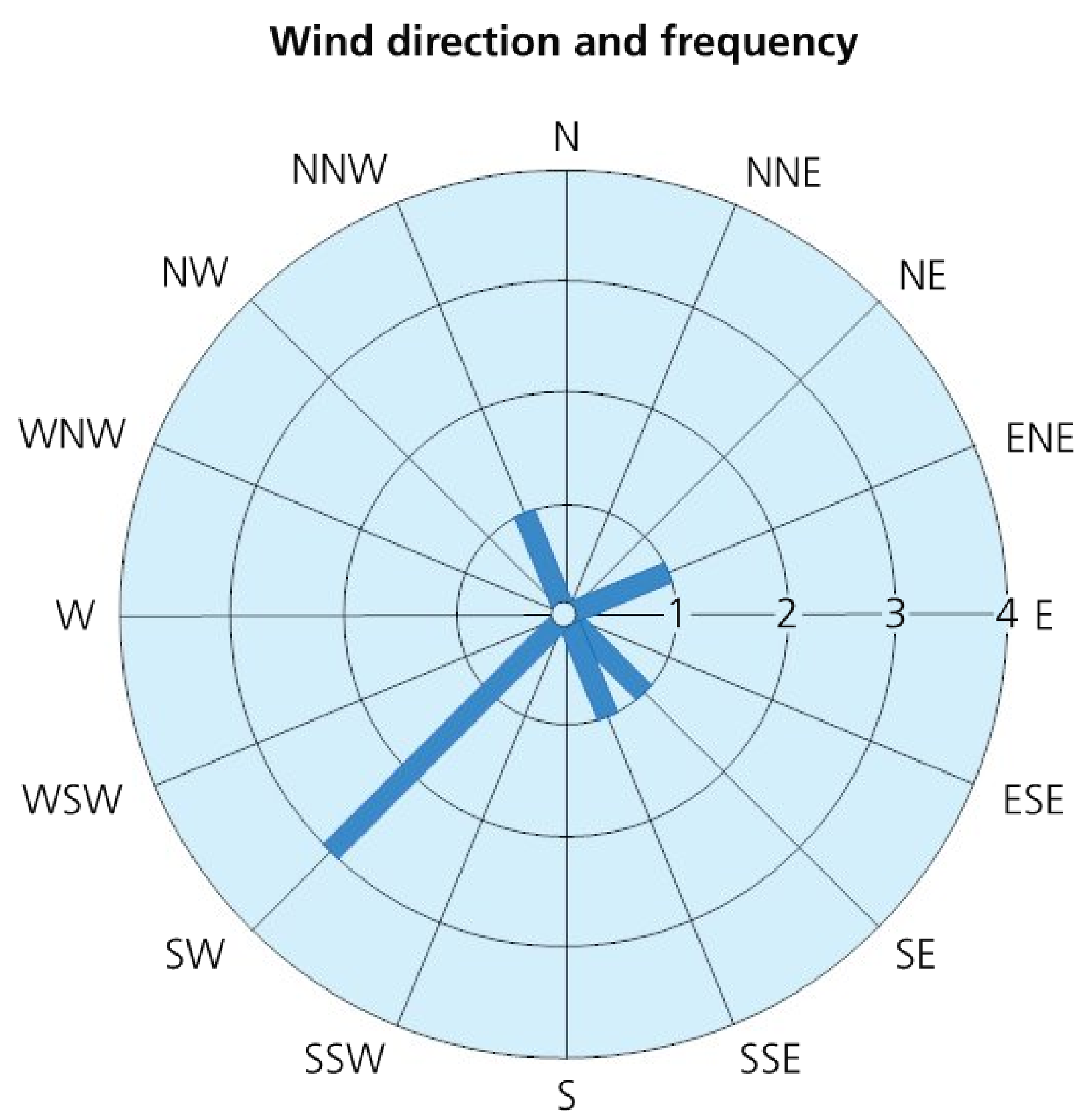
The speed of the wind is measured by an anemometer, which consists of three or four metal cups fixed to metal arms that rotate freely on a vertical shaft. When there is a wind, the cups rotate. The stronger the wind, the faster the rotation. The number of rotations is recorded on a meter to give the speed of the wind in km hr^{-1}.

Pages 89–90

6 a



Daily weather: February



b The maximum temperature was 29.1 °C and the minimum was 11.7 °C.

c The mean minimum temperature was 17.3 °C and the mean maximum temperature was 24.6 °C.

d 15.2 mm of rain fell in the seven days.

e In general, February was warmer, drier and less windy than in August. The mean minimum temperature was 17.3 °C compared with 9.1 °C in August, and the mean maximum temperature was 24.6 °C in February compared with 12.8 °C in August. February was drier – with 15.2 mm of rain, compared with 24.2 mm in August. Wind speeds in February ranged between 9 and 19 km hr^{-1}, whereas in August they were between 20 and 37 km hr^{-1}

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7 a The highest temperatures are found in the built-up area, with temperatures of between 6 °C and 9 °C. In contrast, the minimum temperatures (2–3 °C) were found by the canal. The open space (playing fields) had an intermediate minimum temperature of 5–5 °C.

b The buildings will store some energy by day and slowly release it during the evening. In addition, some of the buildings may have some night-time heating or early morning heating which increases the temperature. In contrast, by the canal there are no additional sources of heating, nor much storage from the daytime.

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8 a i During high pressure there is a greater contrast in the temperature of east- and west-facing walls. The east-facing wall will heat up earlier than the west-facing wall, and it is a few degrees warmer than the west-facing wall until early in the afternoon. The east-facing wall has its peak temperature at about 3 p.m. In contrast, the west facing wall peaks at about 5–6 p.m., and is about 2 °C warmer than the east-facing wall.

ii During low-pressure conditions the temperature differences disappear. Both walls have their minimum temperature around 4 a.m. and their peak, of around 19 °C, at around 4 p.m.

b During high-pressure conditions there is likely to be clear skies and so insolation will fall on the east-facing wall earlier than on the west-facing wall, and then fall on the west-facing wall in the afternoon. In contrast, during low-pressure conditions, winds will cause the air to be mixed, and so there will be less contrast between the temperature of the two walls.

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9 a i In winter, the wind speed over pasture (1–3 m s^{-1}) is greater than in the forest (<0.5 m s^{-1}). There is less variation in air temperature, with pasture slightly warmer (5–10 °C) than the forest (c. 6–8 °C). There is also little variation in soil temperature, 8–9 °C on the pasture, compared with *ca.* 8 °C in the forest.

ii In summer the contrasts are more marked. Wind speed varies between 1 and 3 m s^{-1} in the pasture, but is well below 0.5 m s^{-1} in the forest. There is still little variation in the air temperature, although the forest is cooler in late morning and early afternoon, whereas soil temperature is steady in the forest around 15 °C, but varies between *ca.* 17 °C around 0600 hours and *ca.* 20 °C around 1400 hours in the pasture.

b Wind speed in the forest is much lower (<0.5 m s^{-1}) and stable than in the pasture. With increasing distance from the forest edge, wind speed increases, reaching a maximum of around 2 m s^{-1}. Air temperature in the forest is lower (5 °C at 80 m from the edge rising to *ca.* 8 °C at the forrest edge). In the pasture, air temperature rises to around 11 °C at 20 m from the forest edge and stabilizes at about 10 °C by 80 m. The soil temperature in the forest is around 6–7 °C whereas in the pasture it is higher and more variable (9–11 °C).

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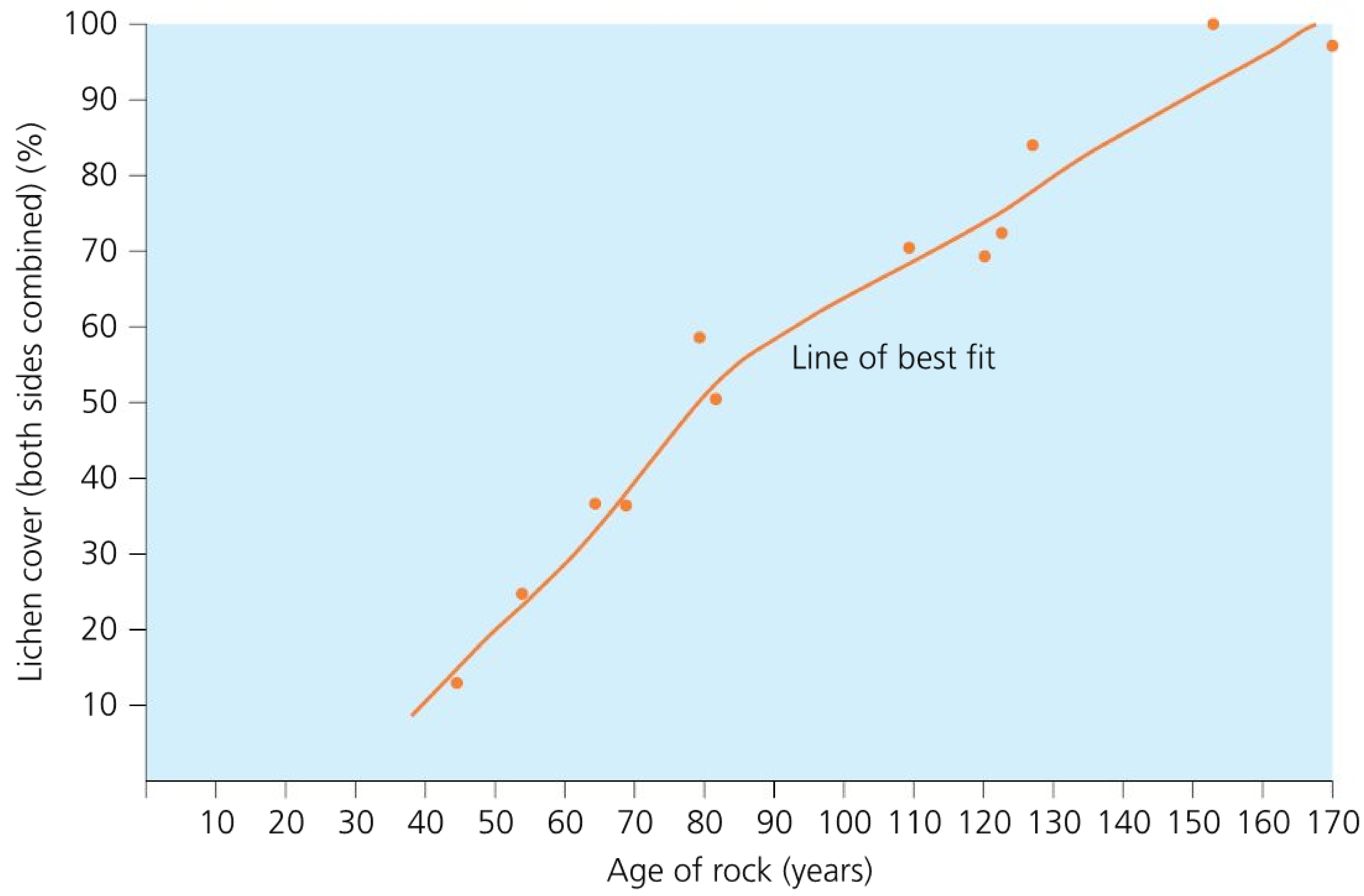
10 a Scatter graph, for example:



Scatter graph to show relationship between age of rock and percentage cover of lichen

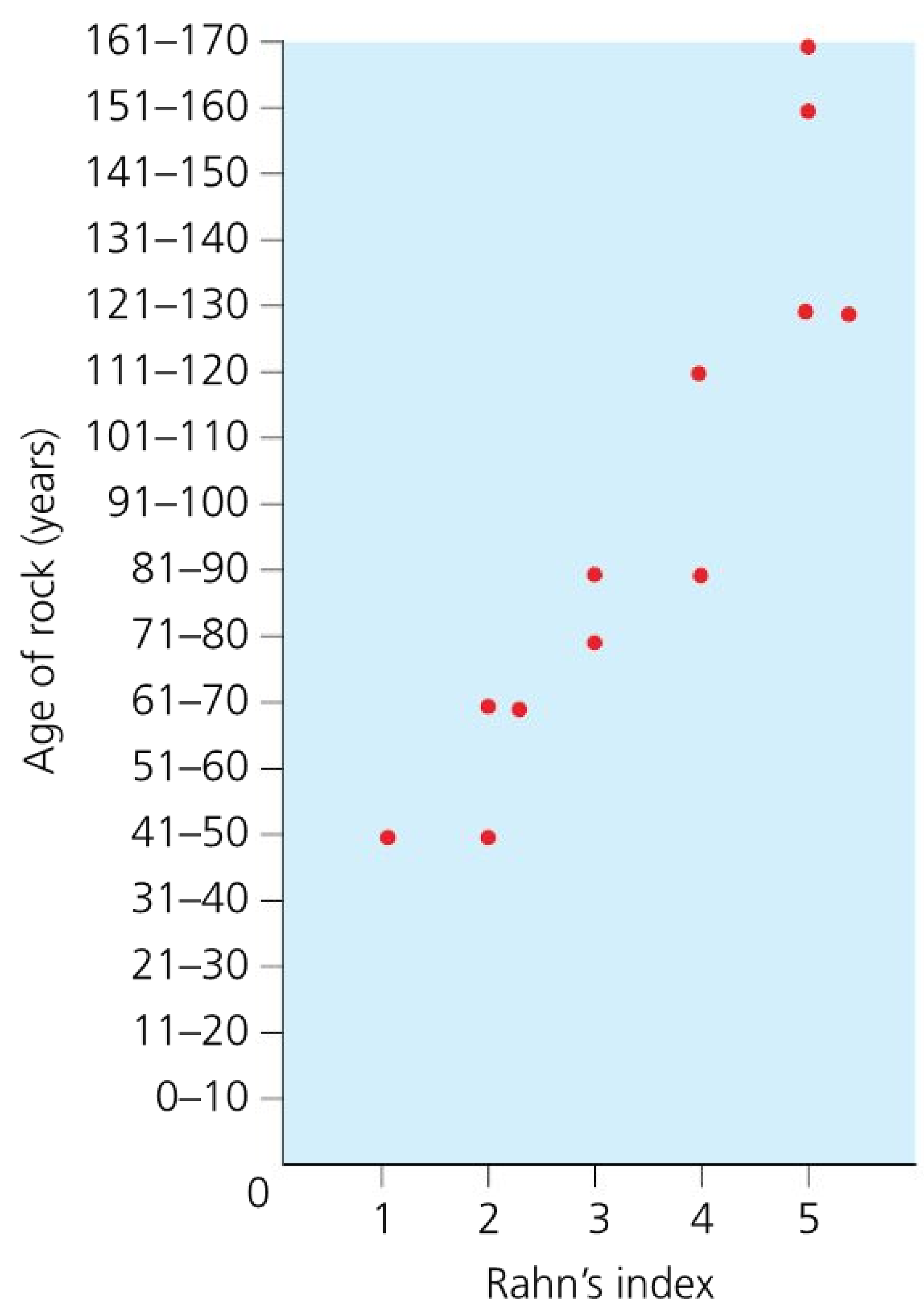
b In general, as the age of the rock increases, the percentage cover of lichen increases. For example, stone 12 which is 44 years old has just 13.5% of lichen cover (on both sides) whereas stone 1 is 170 years old and has 98% lichen cover.

c It is likely that lichen cover will increase with the age of rock, as it is a living organism and grows very slowly. The longer the length of exposure, the more lichen that will be present.

d Anomalies may occur due to gravestones being cleaned, by variations in rock quality (marble may be less porous than sandstone, for example), different grades of the same rock, cost of the rock, position of the rock, for example, exposed or sheltered, under a tree, fallen, etc.

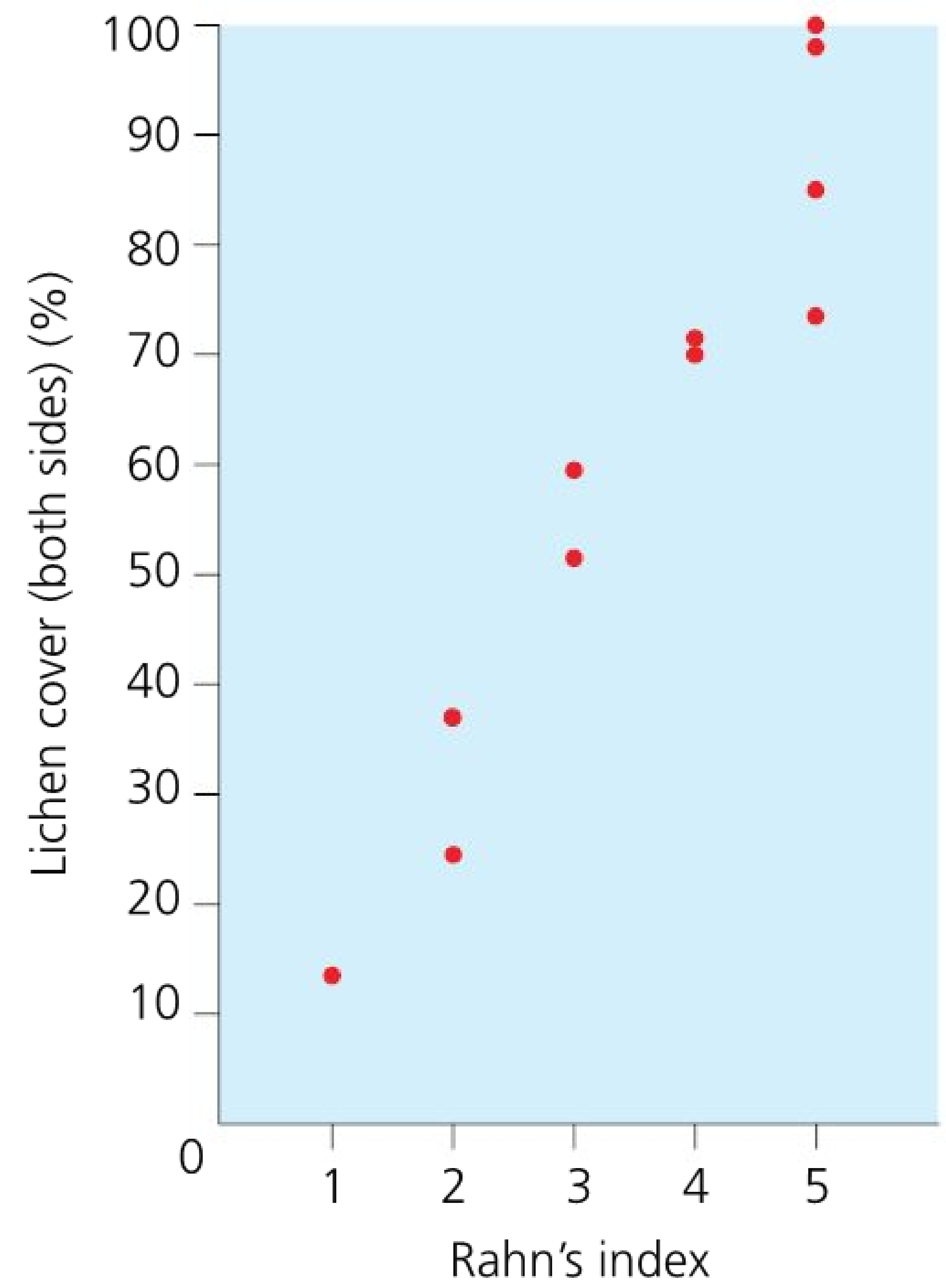
e Diagrams optional.

i As the age of rock increases, Rahn's index increases, for example, the marble rocks aged less than 50 years have an index of 1–2 whereas the limestone rocks of over 150 years have an index of 5.



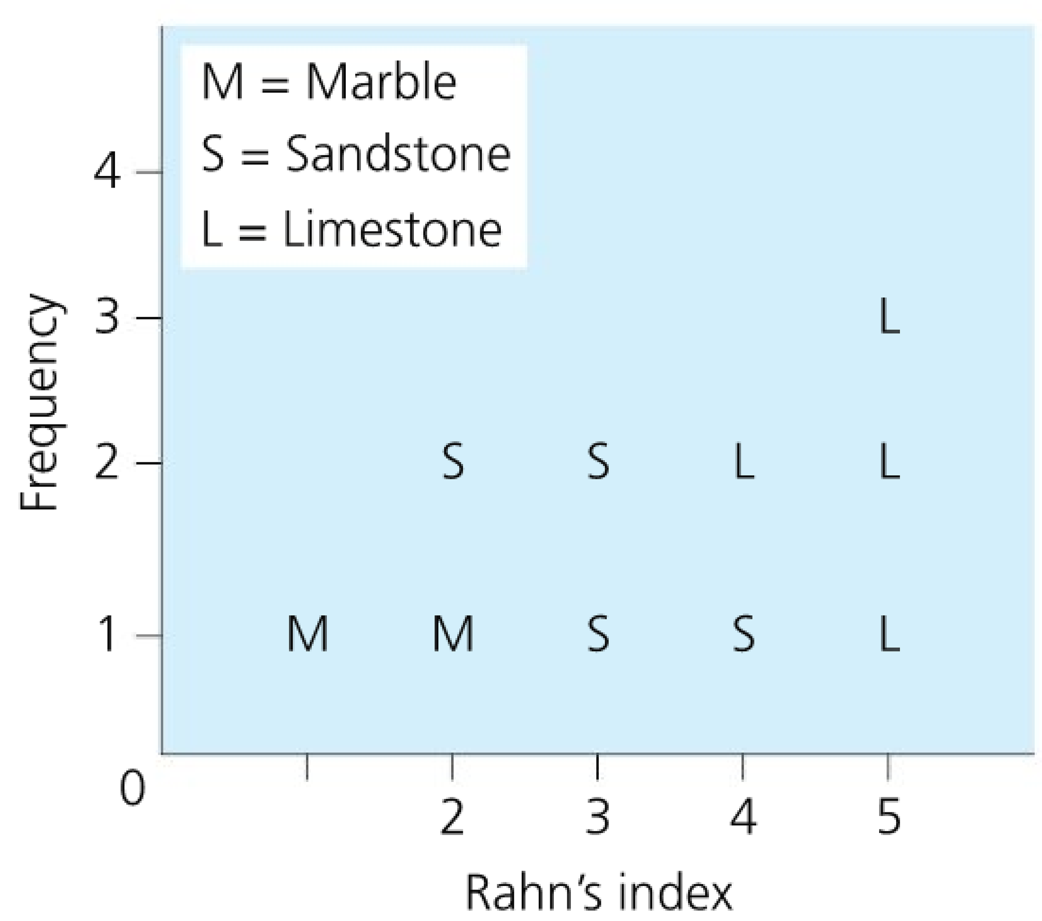
Scatter graph showing age of rock

ii As lichen cover increases, Rahn's index increases. This is because lichen cover increases the weathering of stones and reduces legibility. The greater the length of exposure, the greater the degree of weathering.



Scatter graph showing lichen cover

iii In general, marble rocks have a lower Rahn's index than sandstone or limestone. Limestone has the highest Rahn's index. However, this is more likely to be due to the age of the gravestone rather than the rock itself.



Frequency of rock type

Chapter 7

Page 100

1 **a** CO levels and average temperature in Antarctica appear to be correlated. For example, around 800 000 years ago CO_2 levels were very high, and temperatures were around 4 °C. The same also occurred around 400 000 ago. In contrast, *ca.* 200 000 CO_2 levels were low (*ca.* 200 ppm) and temperatures were around –5 °C.

b **i** Higher CO may lead to increased greenhouse gases and warmer temperatures.

ii Increased temperatures may lead to increased plant growth, and eventually increased release of CO_2 on decomposition of the plants following their death.

iii Positive feedback could cause increased CO_2, leading to increased temperatures, more plant growth and then increased CO as a result of the release of carbon following the death of plants.

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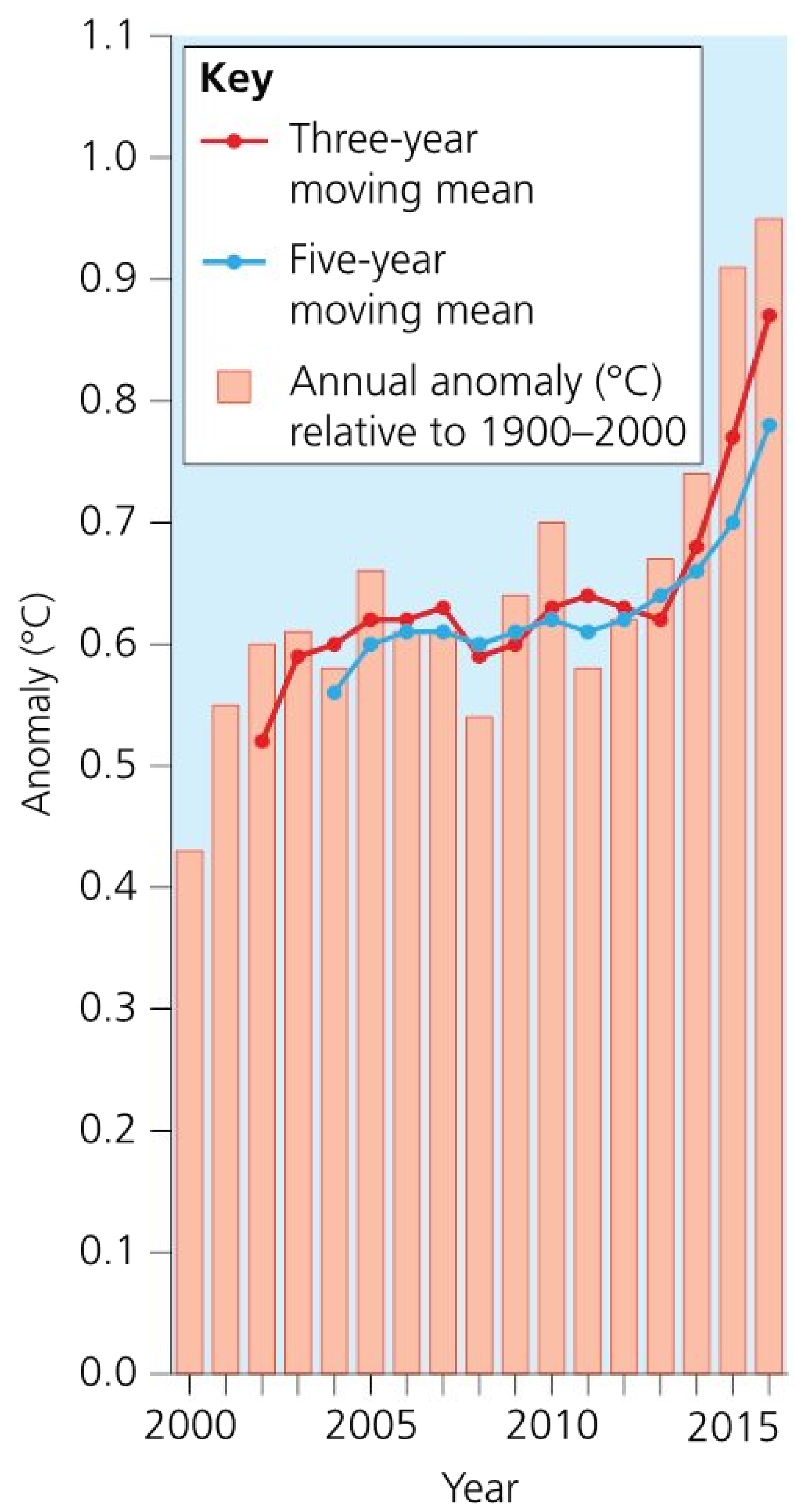
2 a

Five-year moving mean (years)	Five-year moving mean (°C)
2000–2004	0.56
2001–2005	0.60
2002–2006	0.61
2003–2007	0.61
2004–2008	0.60
2005–2009	0.61
2006–2010	0.62
2007–2011	0.61
2008–2012	0.62
2009–2013	0.64
2010–2014	0.66
2011–2015	0.70
2012–2016	0.78

b



Annual temperature anomalies, 2000–2015, and three-year moving mean and five-year moving mean

c The 5-year moving mean is less extreme than the 3-year moving mean and has gentler changes in gradient.

d Moving means allow us to see changes over time, while reducing the impact of year to year changes, which can be quite erratic. It removes the extremes and concentrates on trends.

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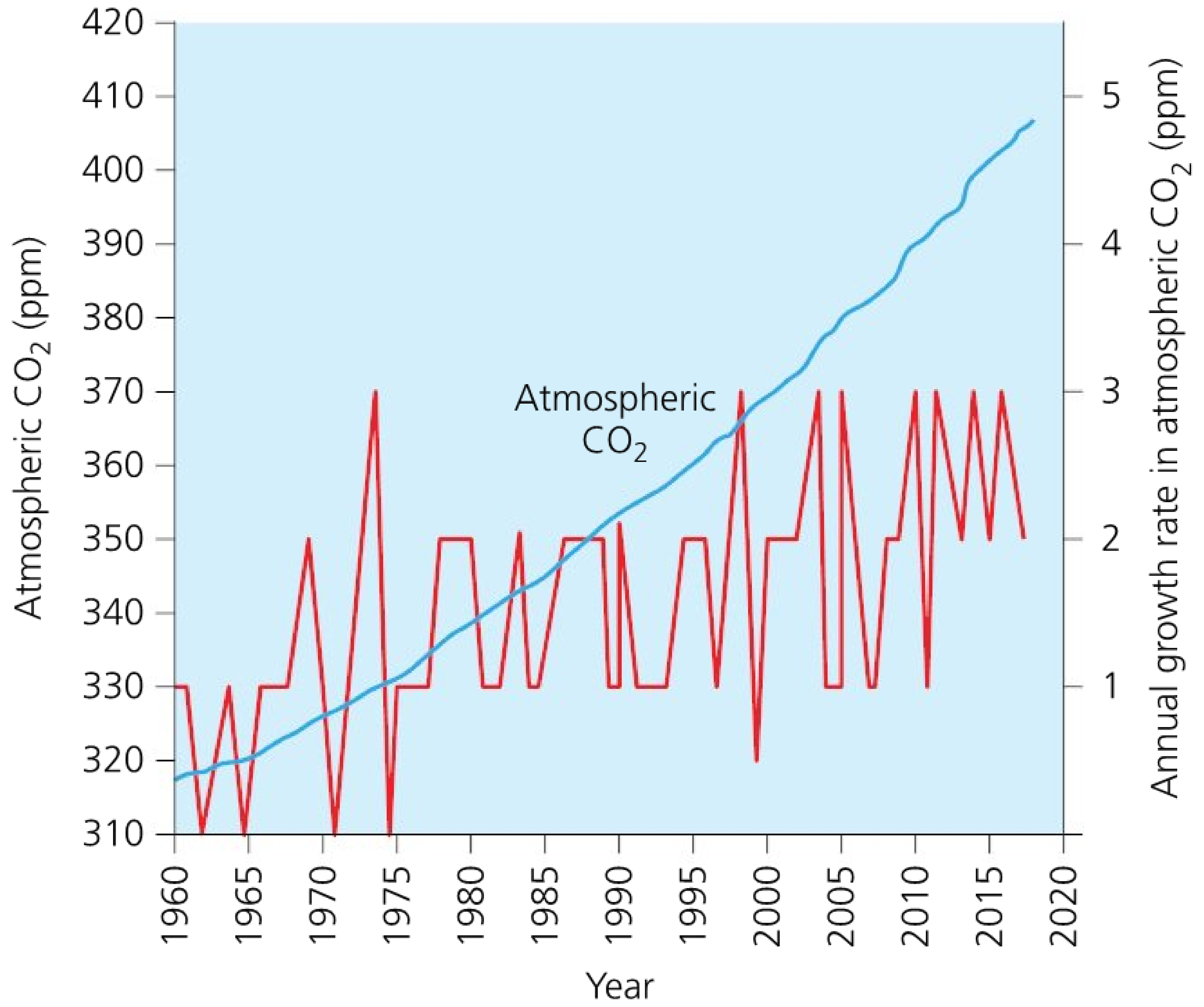
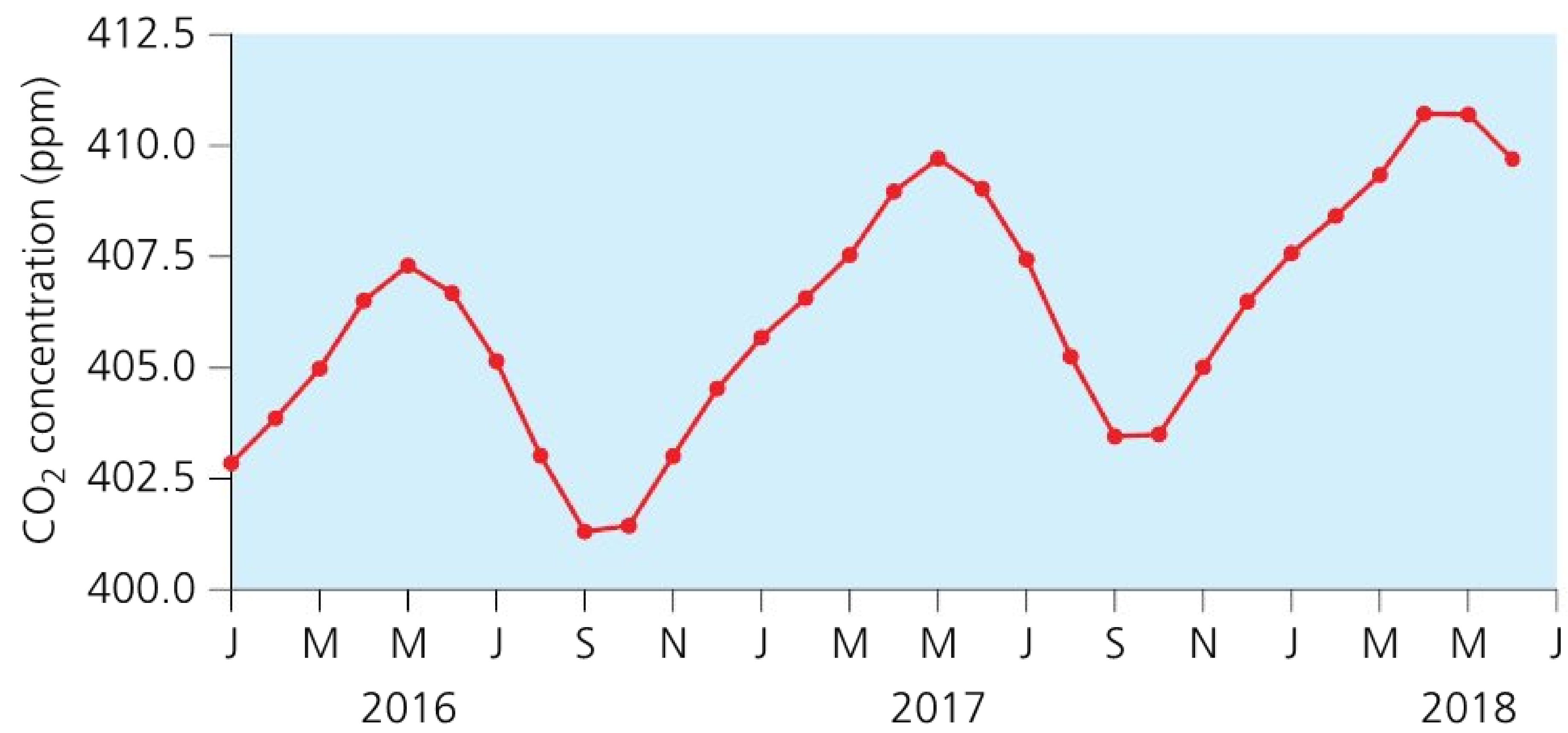
3 a and **b**



Trends in total atmospheric CO_2 (ppm) and annual growth in atmospheric CO_2 (ppm)

4 a



Monthly CO_2 concentration (ppm), January 2016–June 2018

b Two trends include a long-term trend (there is increasing level of CO_2 in the stratosphere) and a seasonal trend (there is an increased level of CO_2 around spring and a reduced level during summer/autumn).

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5 a i Under 10s have a very low carbon footprint, *ca.*<3 mt.

ii 60-year olds have a high carbon footprint, .14 mt.

iii 80-year olds have a high footprint, *ca.*13 mt.

b i The increase in CO_2 emissions is greatest among 8–15 year olds.

ii Very young children have low emissions but as they get older they go to school, begin to socialise, go to the cinema, they have phones/ laptops which increases their CO_2 emissions.

iii In high income countries, and increasingly in middle income countries, those aged around 60 are generally higher income, they have paid for their homes, their dependents may have left home and their disposable income is high, they may travel/ go on holiday frequently.

iv The overall emissions are high, especially for the elderly; life expectancy is high – over 70 years and this is more characteristic of a high income country than a low income country.

v The very old may be immobile (bedridden), they may have ill-health and so eat less, drink less and be housebound.

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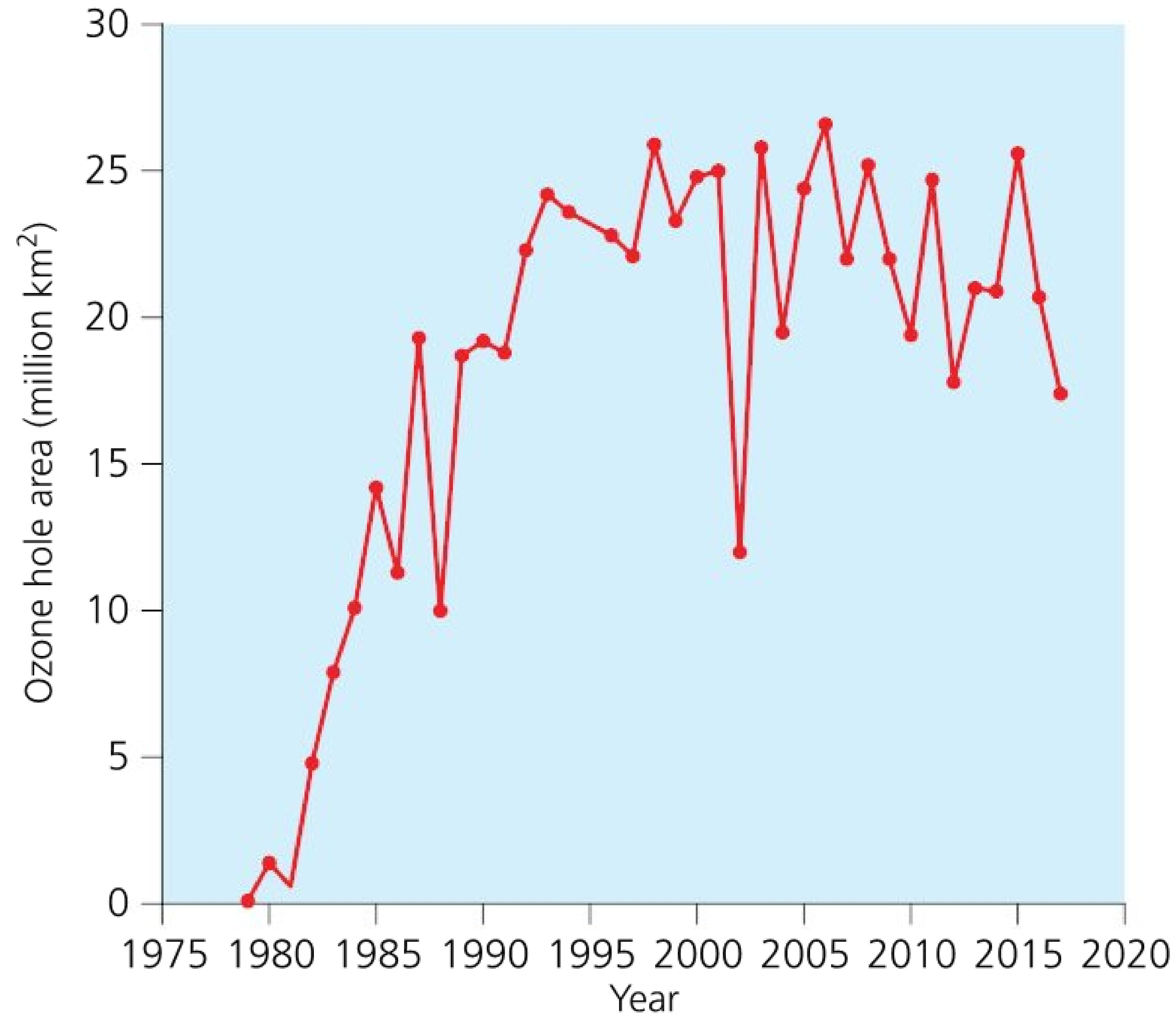
6 a



Ozone hole area (million km^2), 7th September–13th October

b The ozone 'hole' has increased dramatically from 0.1 million km to 26.6 million km^2, an increase of 25,600%. The increase plateaued from around 1990, and there were major declines in the size of the ozone 'hole' in 1998 and 2002. The ozone 'hole' has increased in size and intensity between 1979 and 2006. In 1979, ozone over Antarctica measured between 300–400 DU whereas by 2006 the ozone 'hole' extended all over Antarctica and had thinned to around 200 DU.

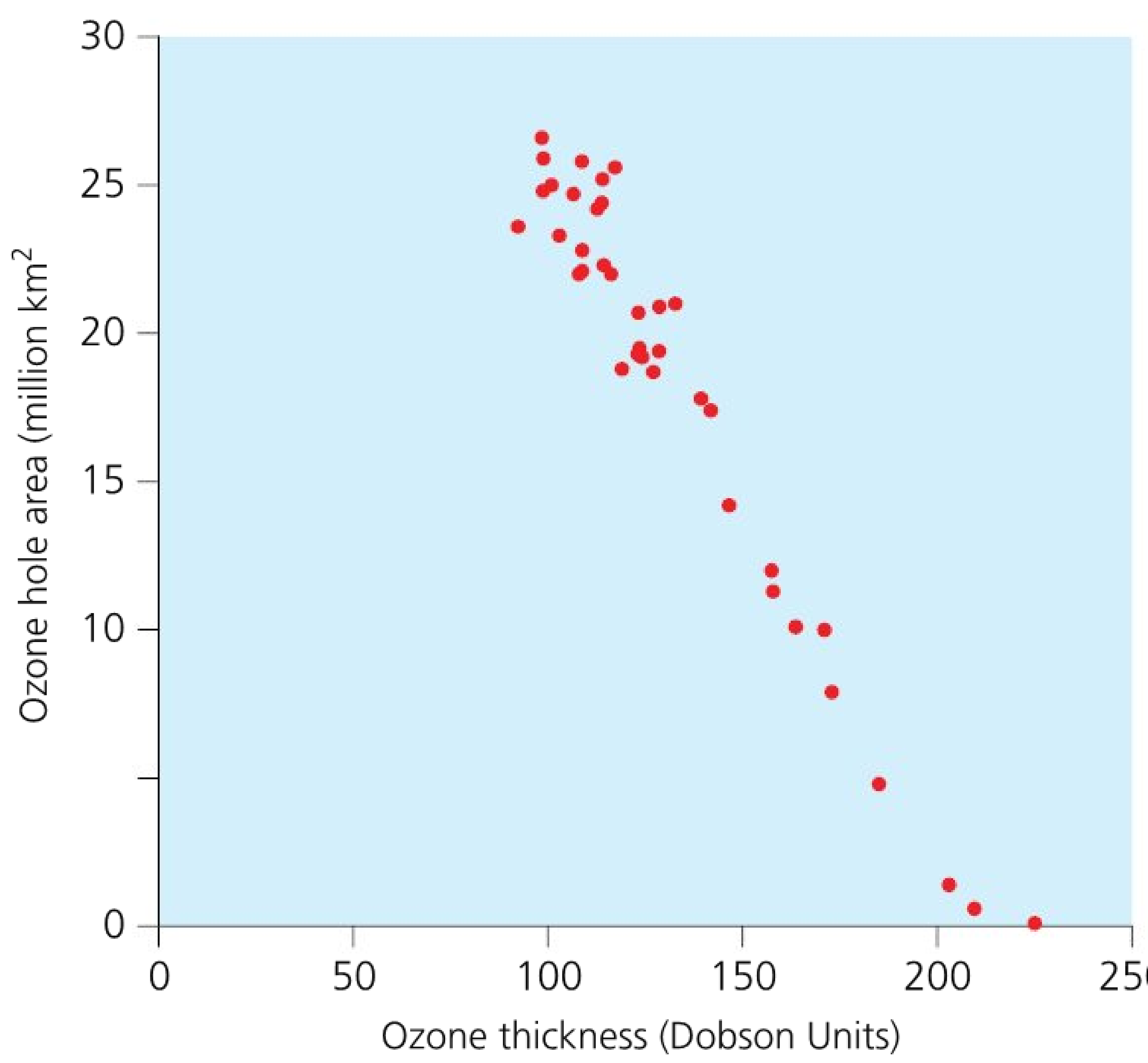
c Student activity involving current value of ozone depletion.

d i Independent value – Dobson Units; Dependent value – size of ozone hole.

ii There is no significant statistical relationship between the amount of ozone (Dobson Units) and the size of the ozone 'hole'.

iii 95% or 99%

iv



Scatter graph to show relationship between ozone thickness (Dobson Units) and the size of the ozone 'hole'

v Spearman's rank Correlation Coefficient.

vi –0.92

vii The critical values for Spearman's rank Correlation for n = 30 are 0.306 at the 95% level, and 0.432 at the 99% level.
We can therefore reject the null hypothesis and accept that there is a significant statistical relationship between the amount of ozone (Dobson Units) and the size of the ozone 'hole' at the 99% level of significance.

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7 a

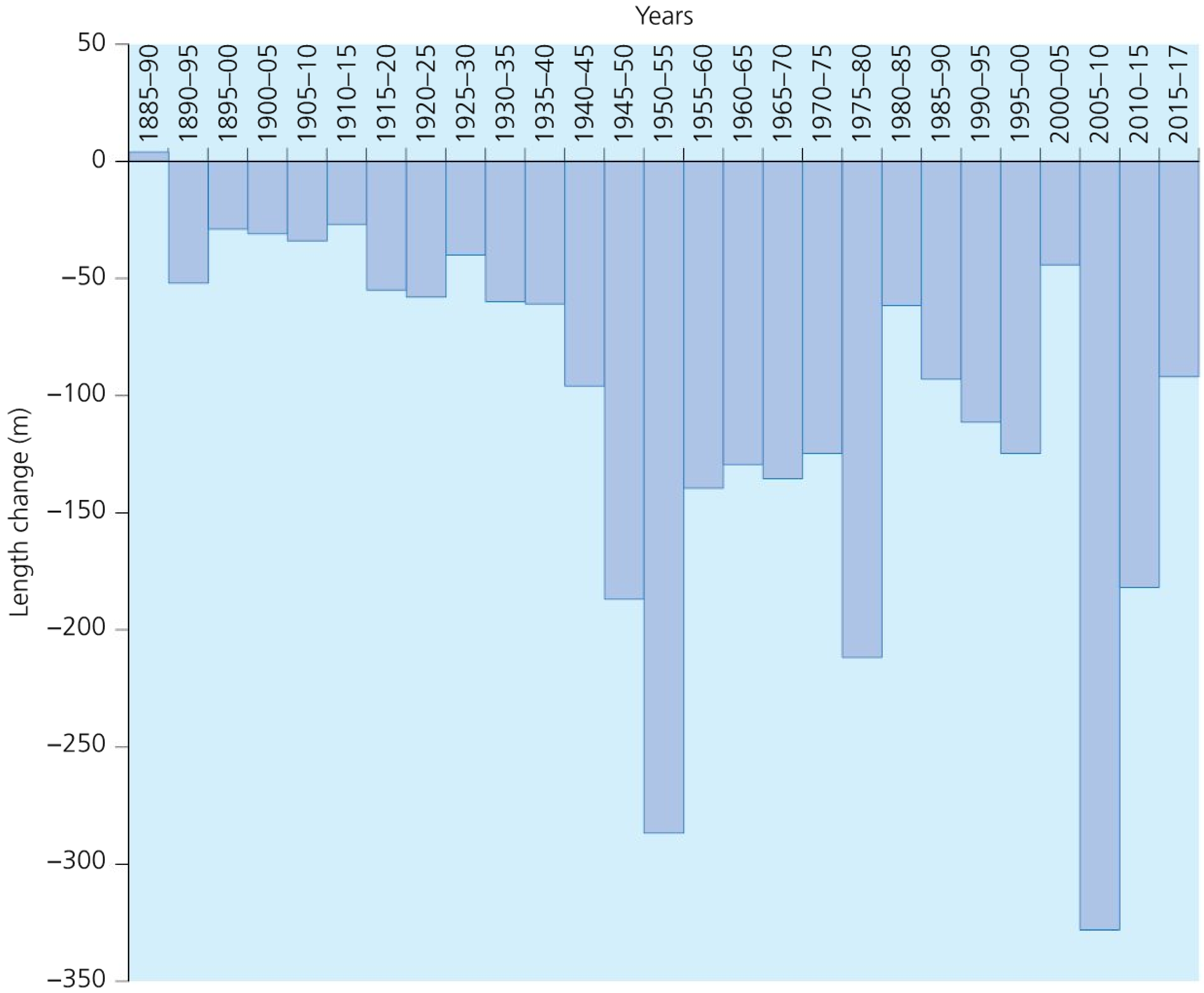
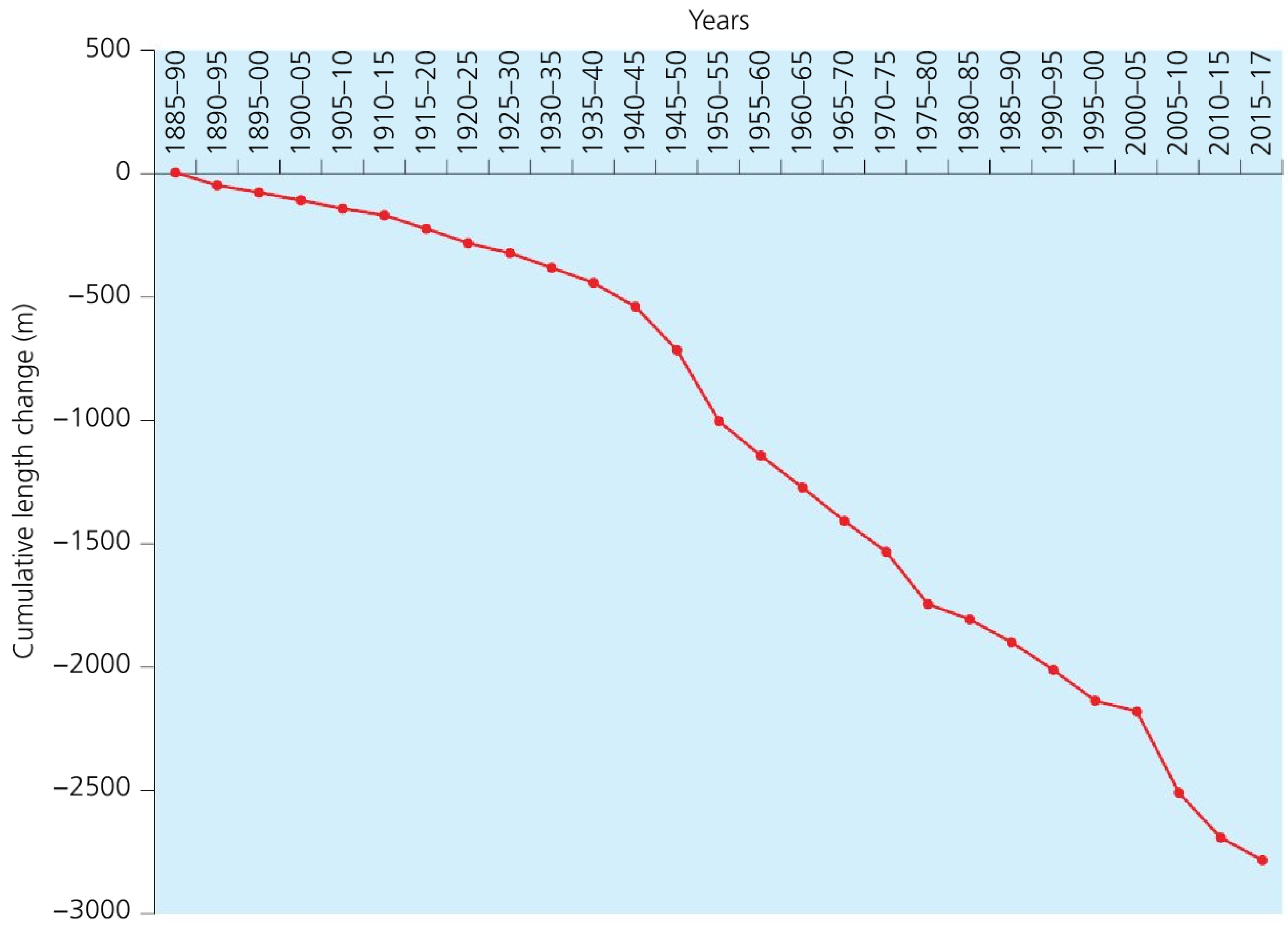


Figure 19 Gorner Glacier – variations in five-year ice loss

b

Years*	Length change (m)	Cumulative length change (m)
1885–90	4	4
1890–95	−52	−48
1895–00	−29	−77
1900–05	−31	−108
1905–10	−34	−142
1910–15	−27	−169
1915–20	−55	−224
1920–25	−58	−282
1925–30	−40	−322
1930–35	−60	−382
1935–40	−61	−443
1940–45	−96	−539
1945–50	−187	−716
1950–55	−287	−1003
1955–60	−139.7	−1142.7
1960–65	−129.5	−1272.2
1965–70	−135.6	−1407.8
1970–75	−124.9	−1532.7
1975–80	−212	−1744.7
1980–85	−61.7	−1806.4
1985–90	−93.1	−1899.5
1990–95	−111.5	−2011
1995–00	−124.8	−2135.8
2000–05	−44.2	−2180
2005–10	−324.4	−2508.4
2010–15	−182	−2690.4
2015–17	−92	−2782.4

c



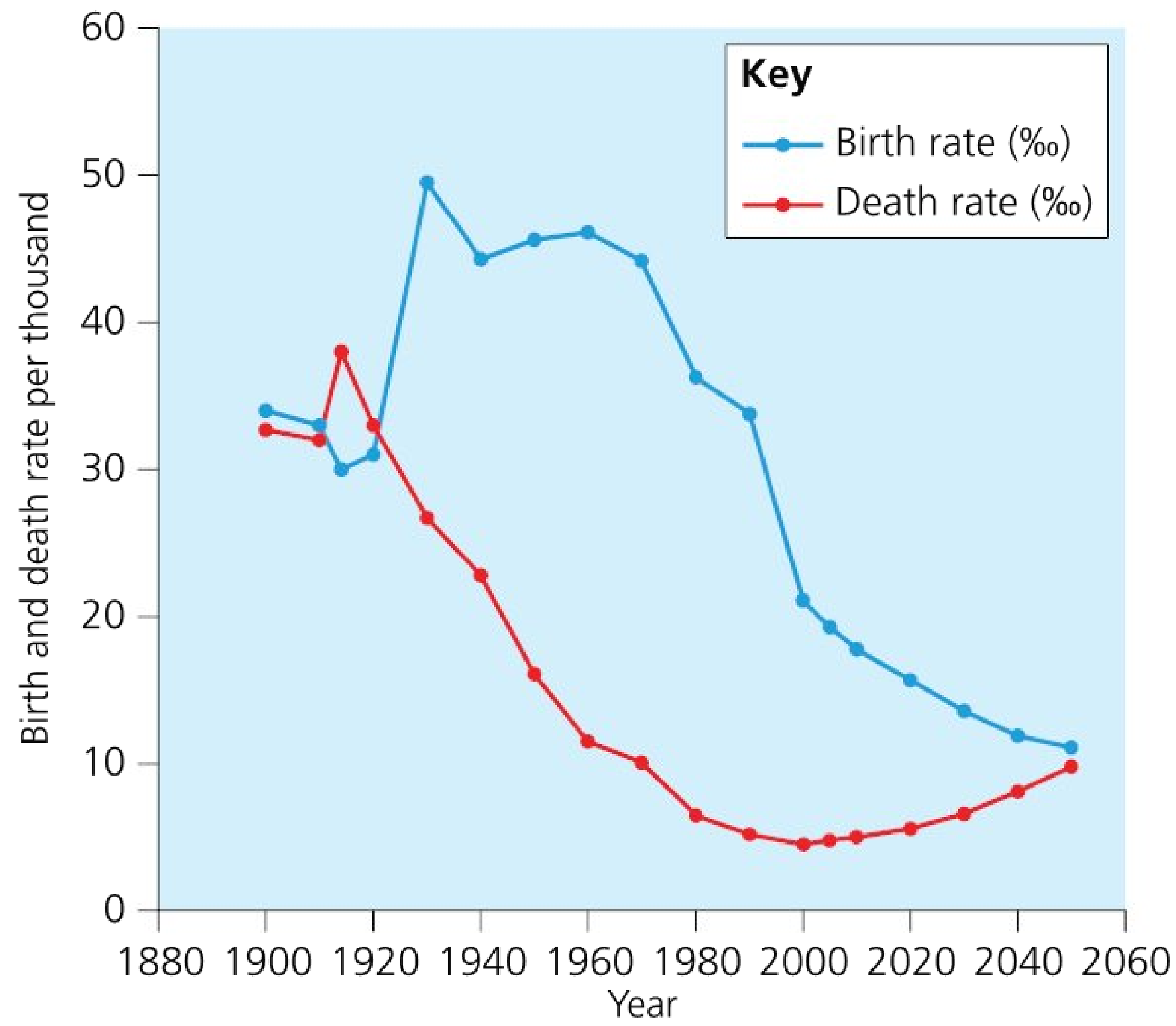
Gorner Glacier – cumulative length loss

d Apart from 1895–1890, when the Gorner Glacier advanced by 4 m, there has been continuous decline, reaching a total of 2782.4 m by 2017. This decline has not been steady – there were major declines in 1950–5 and 2005–10. The decline in glacier length is consistent with global climate change.

Chapter 8

Pages 109–110

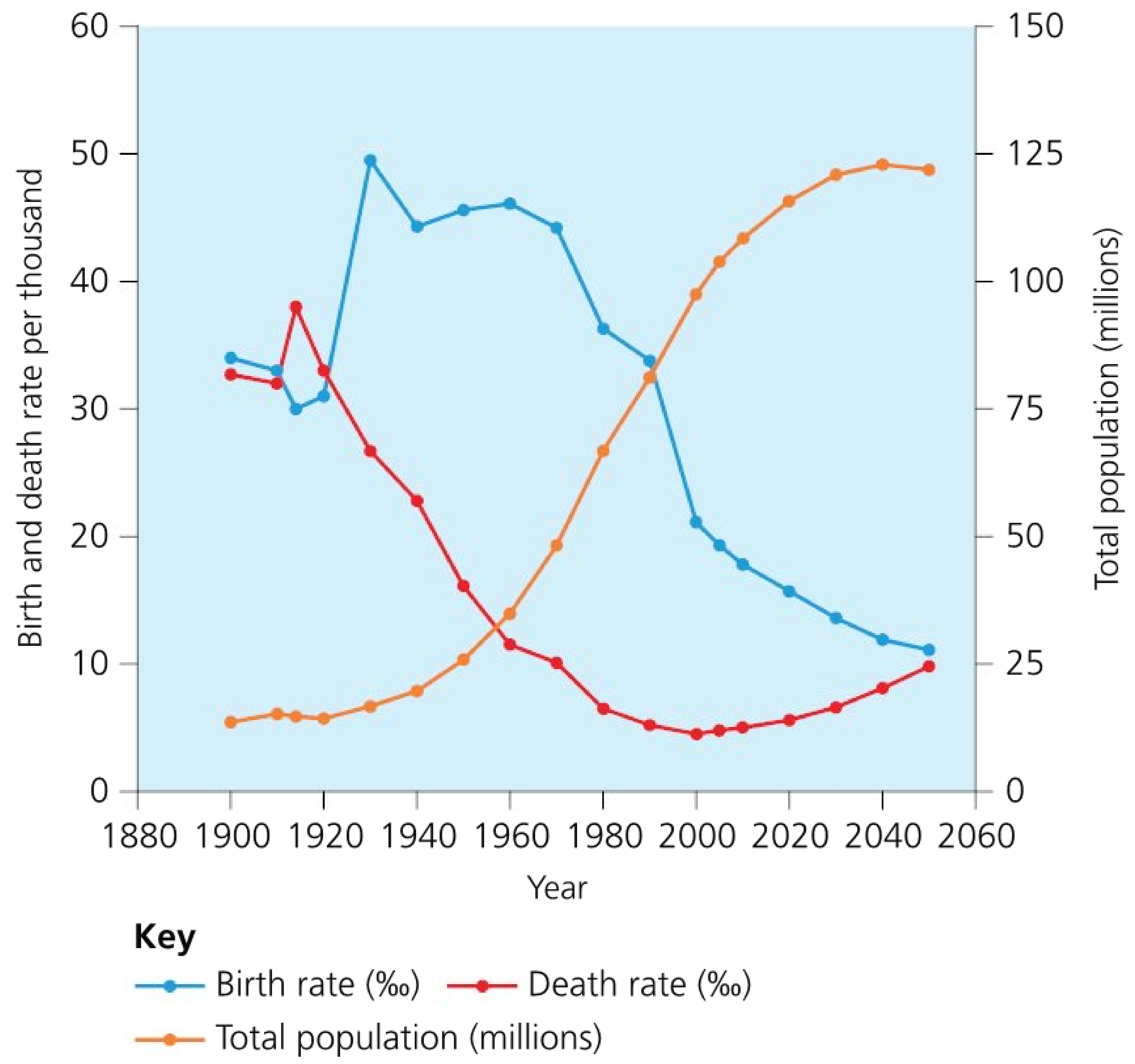
1 a



Mexico's birth and death rate (‰), 1900–2050

b Rates are very high and variable up to *ca.* 1920 (stage 1 of the DTM). Between 1930 and 1970 birth rates become very high (over 40%) but death rates fall (stage 2 of the DTM). From 1980, the birth rate begins to fall but the death rate is very low (stage 3 of the DTM). It is projected that from 2040 the birth rate and death rate will be low and variable (stage 4 of the DTM).

c



Graph of Mexico's birth and death rates

d Mexico's population growth is slow (and in some years negative) at first, between 1900 and 1930. It then grows rapidly from around 15 million to over 100 million between 2000 and 2005. It is predicted to peak at just under 125 million in 2040, and then to decline slowly.

e

Year	Natural increase (%)
1900	0.13
1910	0.10
1914	−0.8
1920	−0.2
1930	2.8
1940	2.15
1950	2.95
1960	2.46
1970	3.41
1980	2.98
1990	2.86
2000	1.66
2005	1.45
2010	1.28
2020	1.01
2030	0.7
2040	0.38
2050	0.13

f In 1900 natural change was low, and there was a period of natural decrease between 1914 and the 1920s. This was most likely due to poor access to clean water and sanitation, poor food supplies and general living standards. Between 1930 and 1970 the death rate declined due to better food supplies and better access to clean water and sanitation. Birth rates remained high as children were a bonus for families working in farming. However, by 1980 the birth rate had fallen as the country had urbanized and industrialized and children were not as much of an asset as before, and most women were now working. By 2050 it is projected that natural change will fall, as the country ages.

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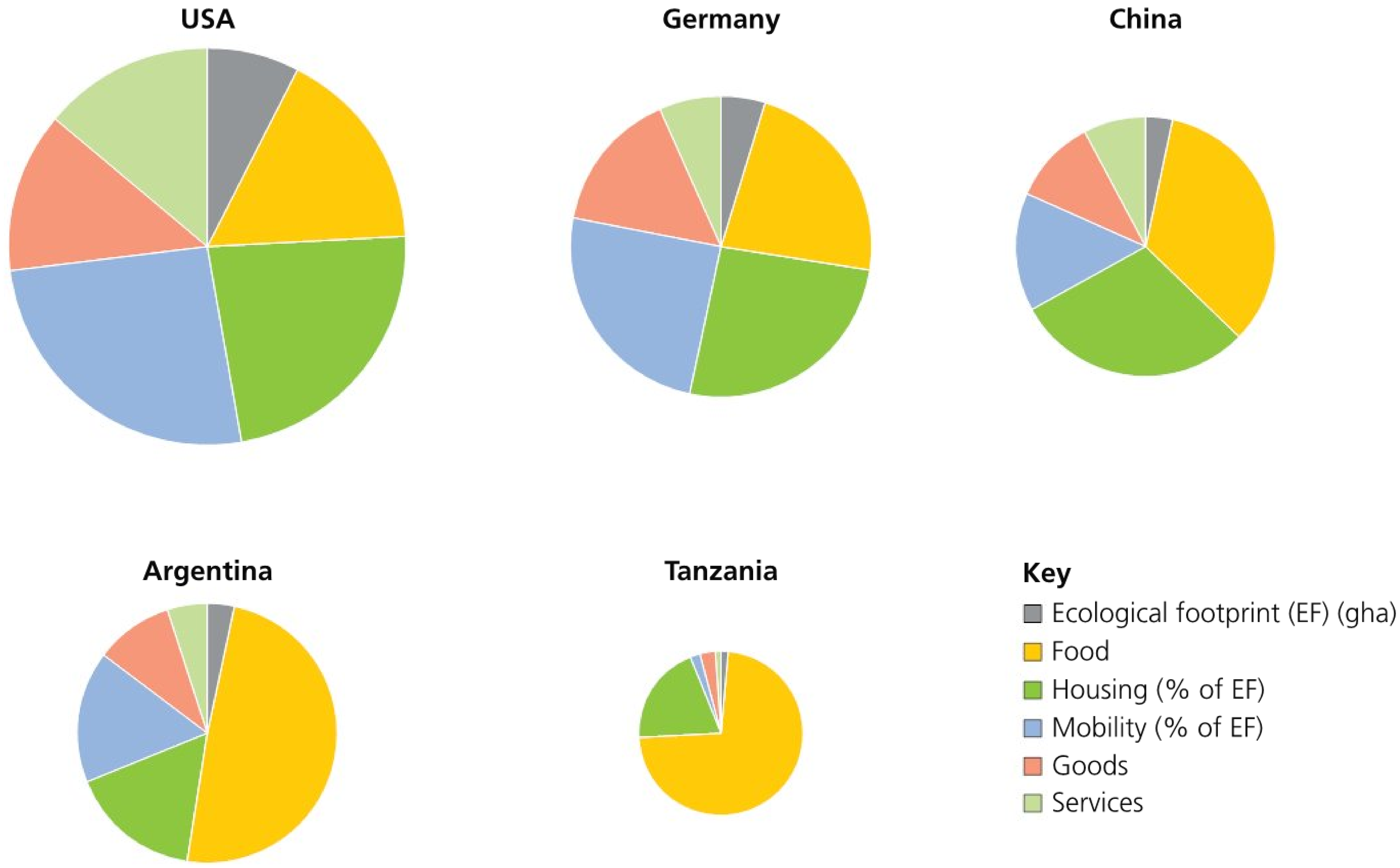
2 a



EFP for USA, Germany, China, Argentina and Tanzania

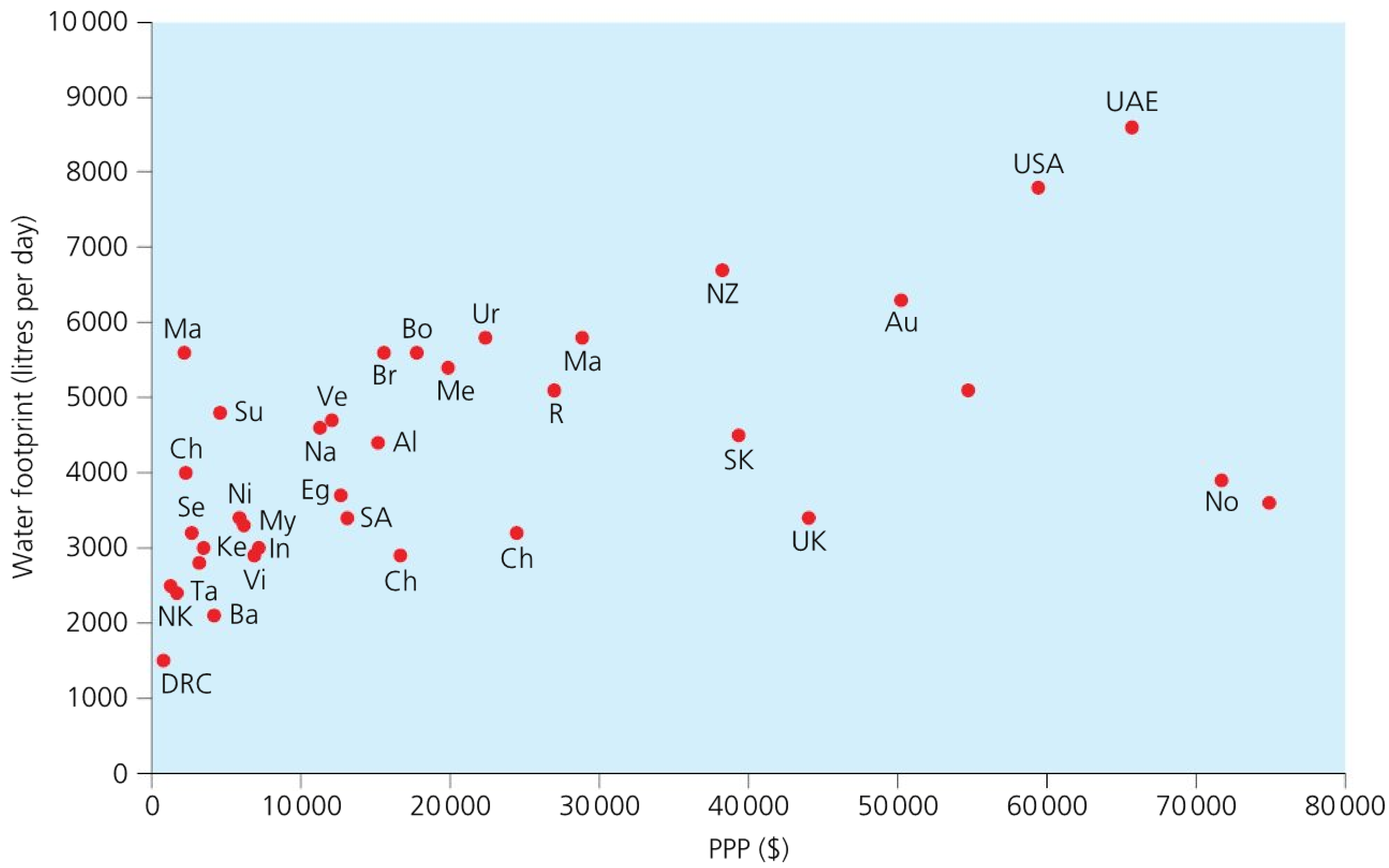
b USA has a large ecological footprint (EFP). Mobility (transport) is the largest component (28%) followed by housing and food. In contrast, Tanzania's ecological footprint is very small, less than 20% that of the USA. It comes mainly from food (almost three-quarters of its EFP), and then from farming (*ca.* one-fifth).

c China and Argentina have the same size EFP. The contribution from the food sector is the highest contributor for both countries – but it accounts for over half of Argentina's EFP and around one-third of China's EFP.

d The EFP of high-income countries is much higher than that of low-income countries (LICs) due to the higher personal consumption of energy, water and food by residents, and also the increased imports of materials from around the world. In LICs, most of the EFP is associated with food production and consumption.

Pages 114–115

3 a



Scatter graph to show the relationship between PPP and water footprints

b In general, as PPP increases, water footprint increases. For example, DRC has a PPP of $800 and a water footprint of 1 500 litres/person/day whereas the USA has a PPP of $59 500 and a water footprint of just 7 800 litres/person/day. There are anomalies, for example, Ireland has a PPP of $75 000 and a water footprint of just 3 600 litres/person/day.

c Spearman's rank = 0.62. The critical values for Spearman's rank correlation for *n* = 30 (we have 36 readings here so the critical values will be even lower) are 0.306 at the 95% level, and 0.432 at the 99% level. We can therefore reject the null hypothesis and accept that there is a significant statistical relationship between PPP and water footprint.

Pages 115–117

4 a
1. USA
2. Saudi Arabia
3. China
4. Uruguay
5. North Korea

b Spearman's rank, 0.89, 99% level of significance that there is a relationship between PPP and carbon footprint (and is stronger than between PPP and water footprint)

Chapter 14

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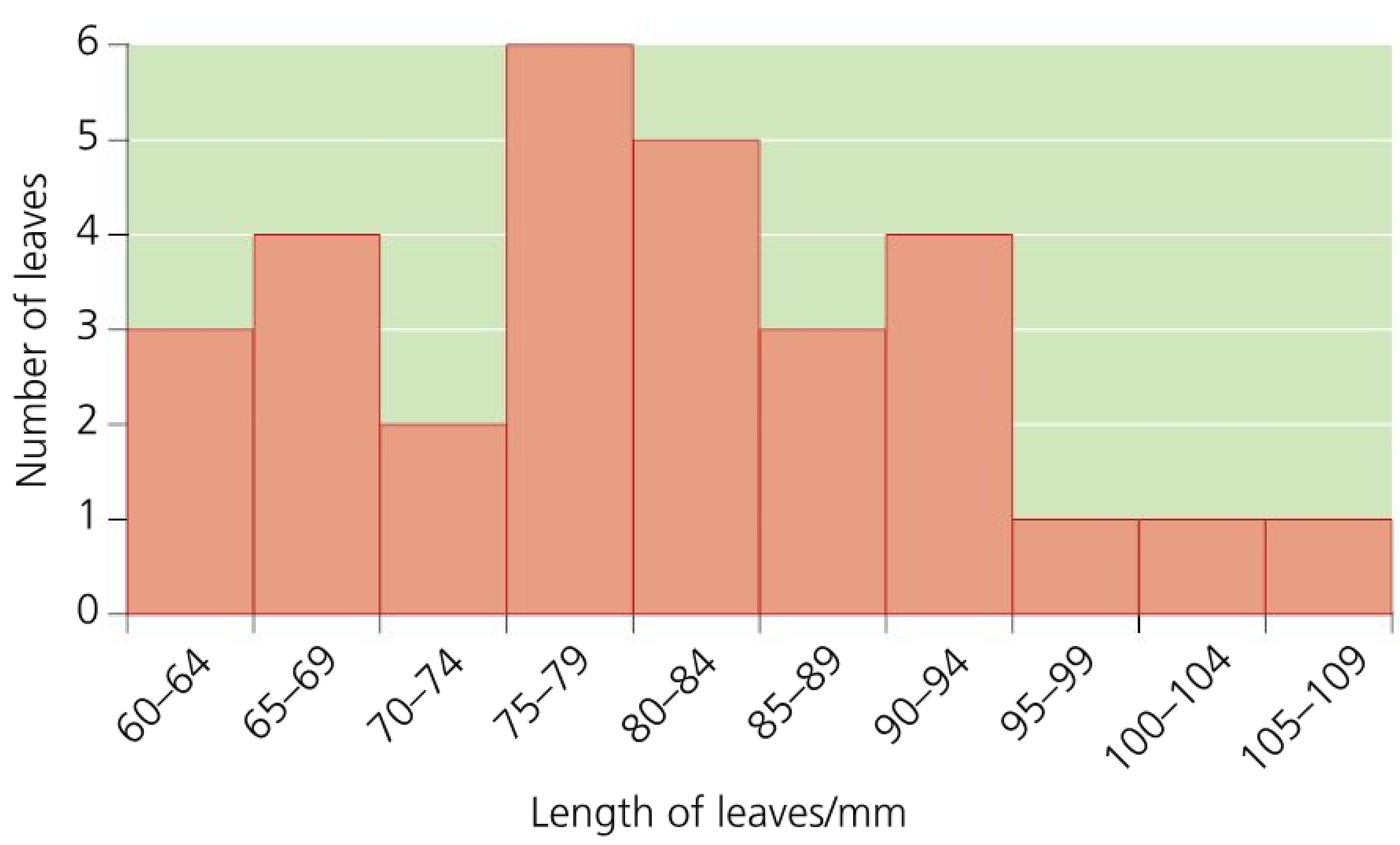
Histograms and bar charts

In histograms, the groups are shown at intervals along the *x*-axis and there is no 'overlap' between groups so any value can only belong to one group. The number of values in each group, or frequency, is shown on the *y*-axis. This type of graph is often known as a frequency histogram.

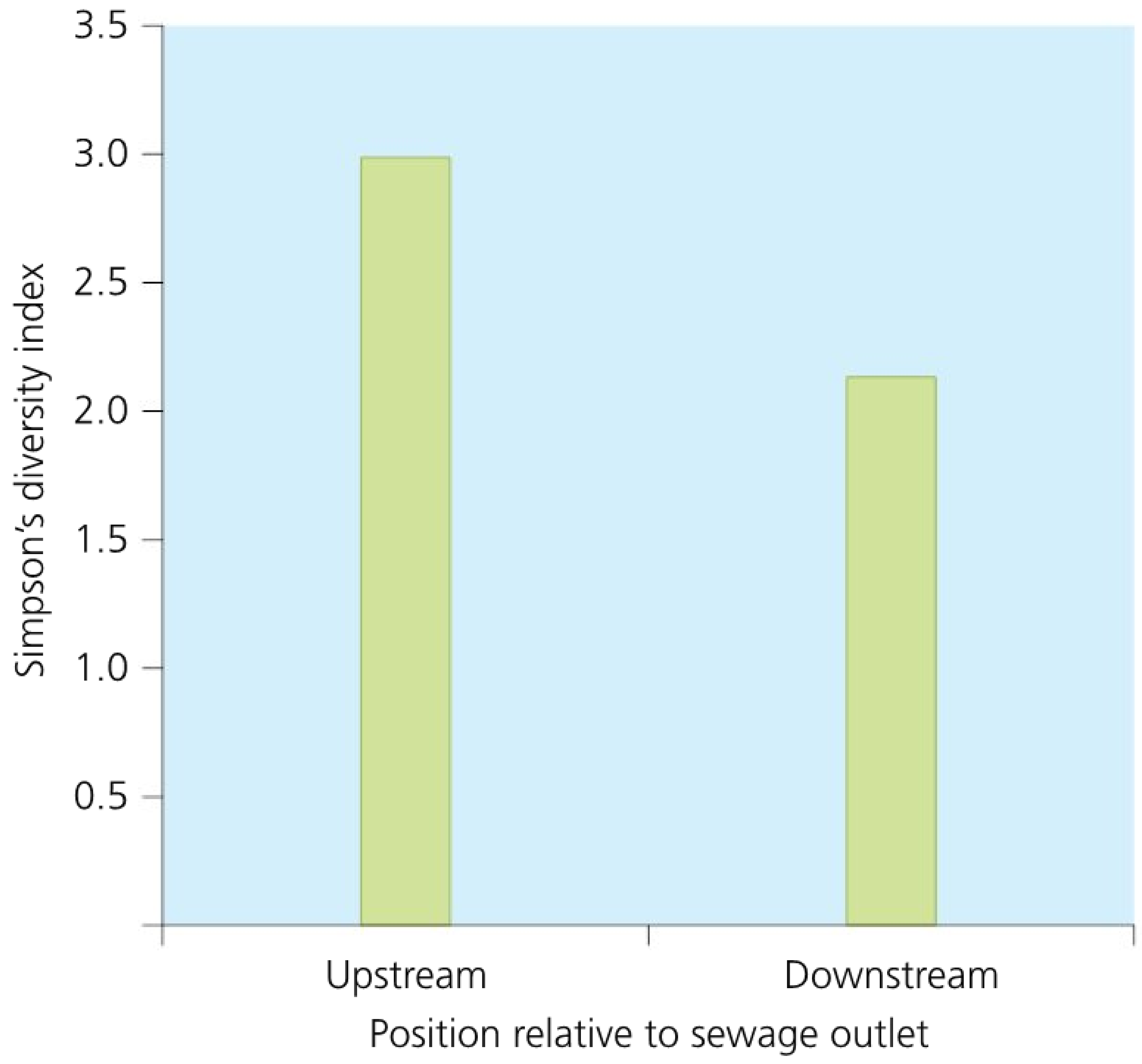
Expert tip

If you are analysing raw data then you may wish to draw a frequency histogram to see if the data show a normal distribution.



Histogram of leaf length data for holly leaves

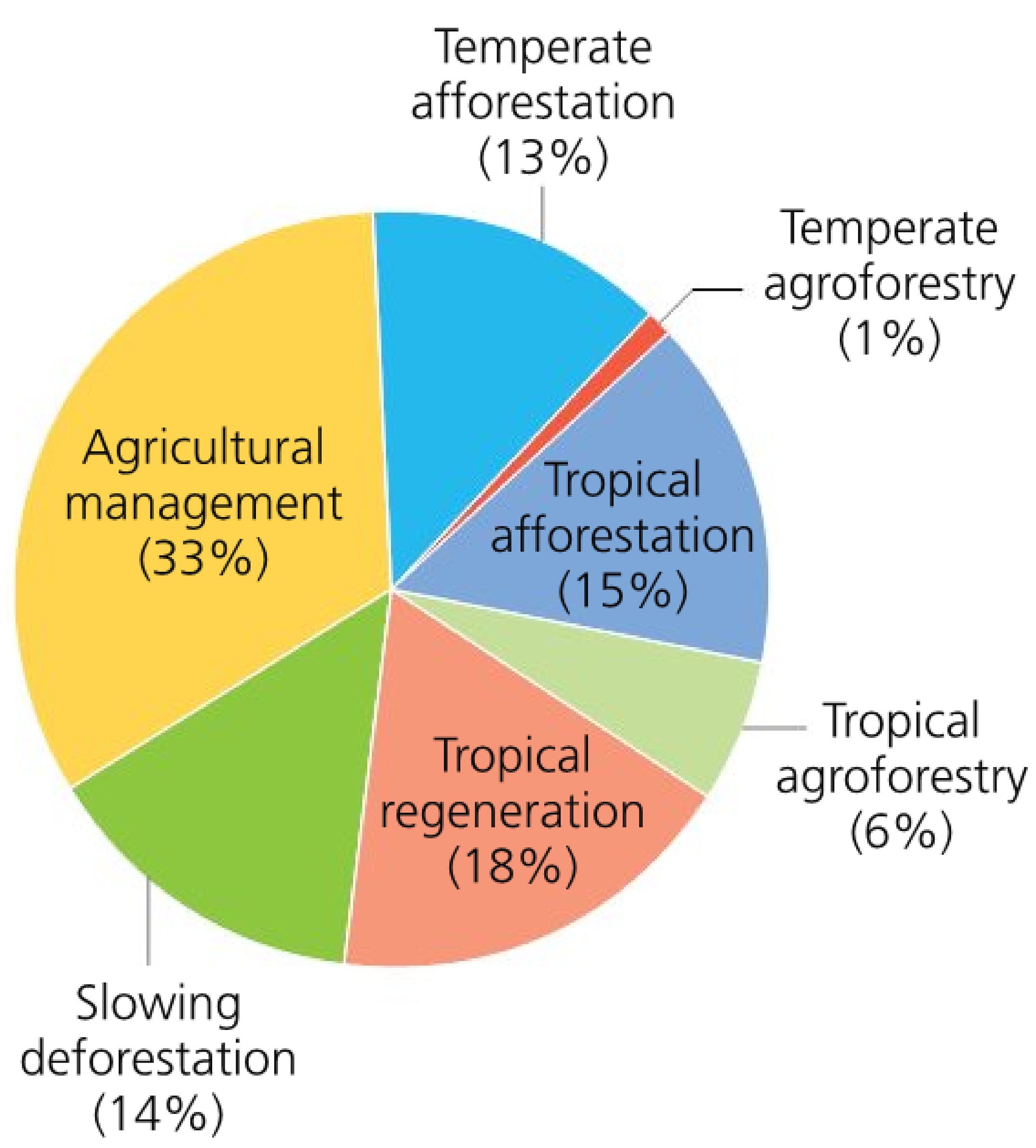
Bar charts (see next figure) are drawn where the independent variable is made up of a number of different, discrete categories and the dependent variable is continuous. The blocks can be arranged into any order, but it can help with comparisons if they are arranged in descending/ascending order of size.



A simple bar chart showing differences in diversity index from two sites, one above a sewage outlet and one just downstream from the sewage outlet. Diversity index calculated using aquatic invertebrates sampled at both sites

Pie charts

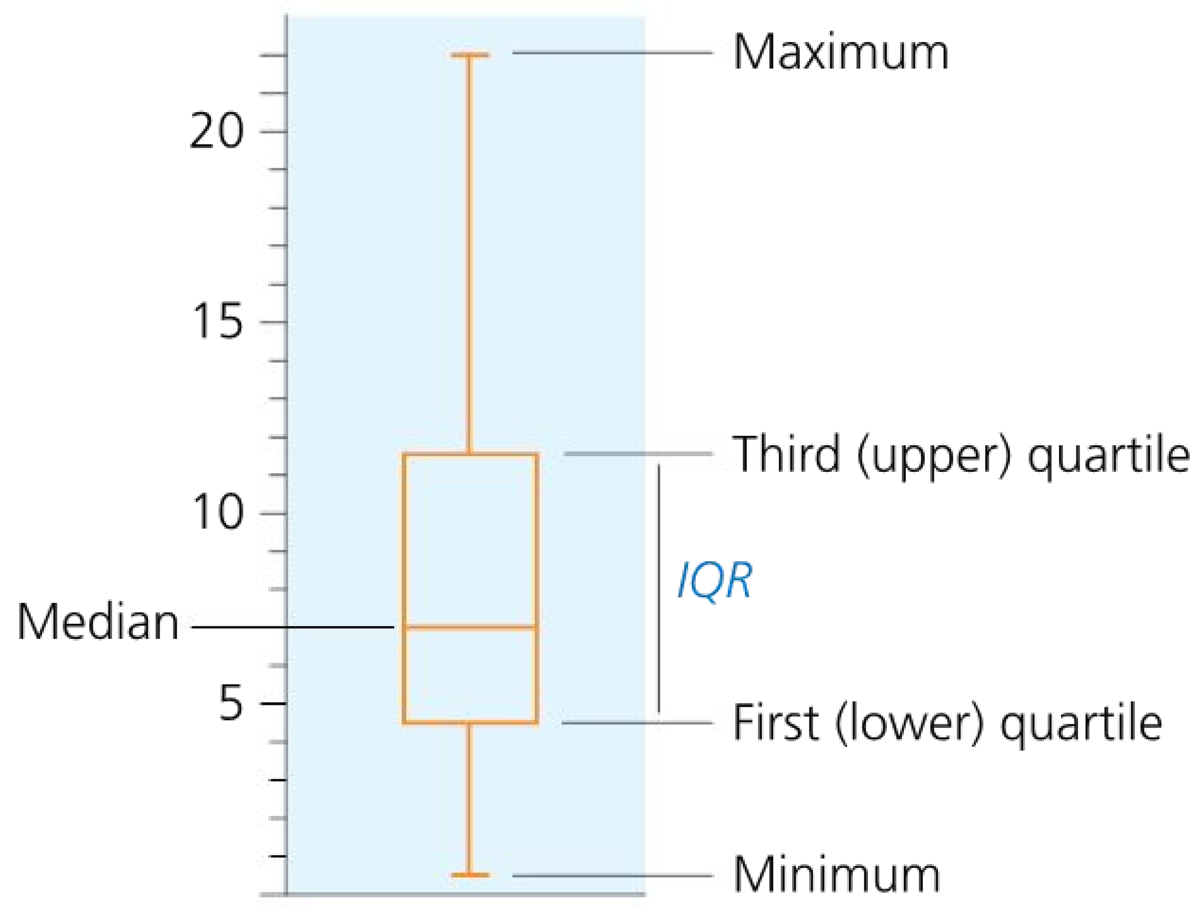
Pie charts are circular graphs used to plot proportional data. The circle represents the whole and is divided into sectors, each of which is proportional to the size of the sample. The sample values are converted to percentage figures and the size of the sector is determined by calculating the angle which will correspond to the percentage. A pie chart is normally drawn with the sectors in rank orders starting at the 12 o'clock position and moving in a clockwise direction.



An example of a pie chart, showing the potential of various land-management activities to mitigate global emissions of CO_2

Box-and-whisker plots

For data tables with non-parametric data, the appropriate descriptive statistics are medians and quartiles, and the appropriate graph is a box-and-whisker plot. The ticks at the tops and bottoms of the vertical lines show the highest and lowest values in the set of data. The top of each box shows the upper quartile, the bottom of each box shows the lower quartile, and the horizontal line represents the median. In the simplest box plot the central rectangle spans the first quartile to the third quartile (the interquartile range, or IQR). A line inside the rectangle indicates the median and 'whiskers' above and below the box show the minimum and maximum values.



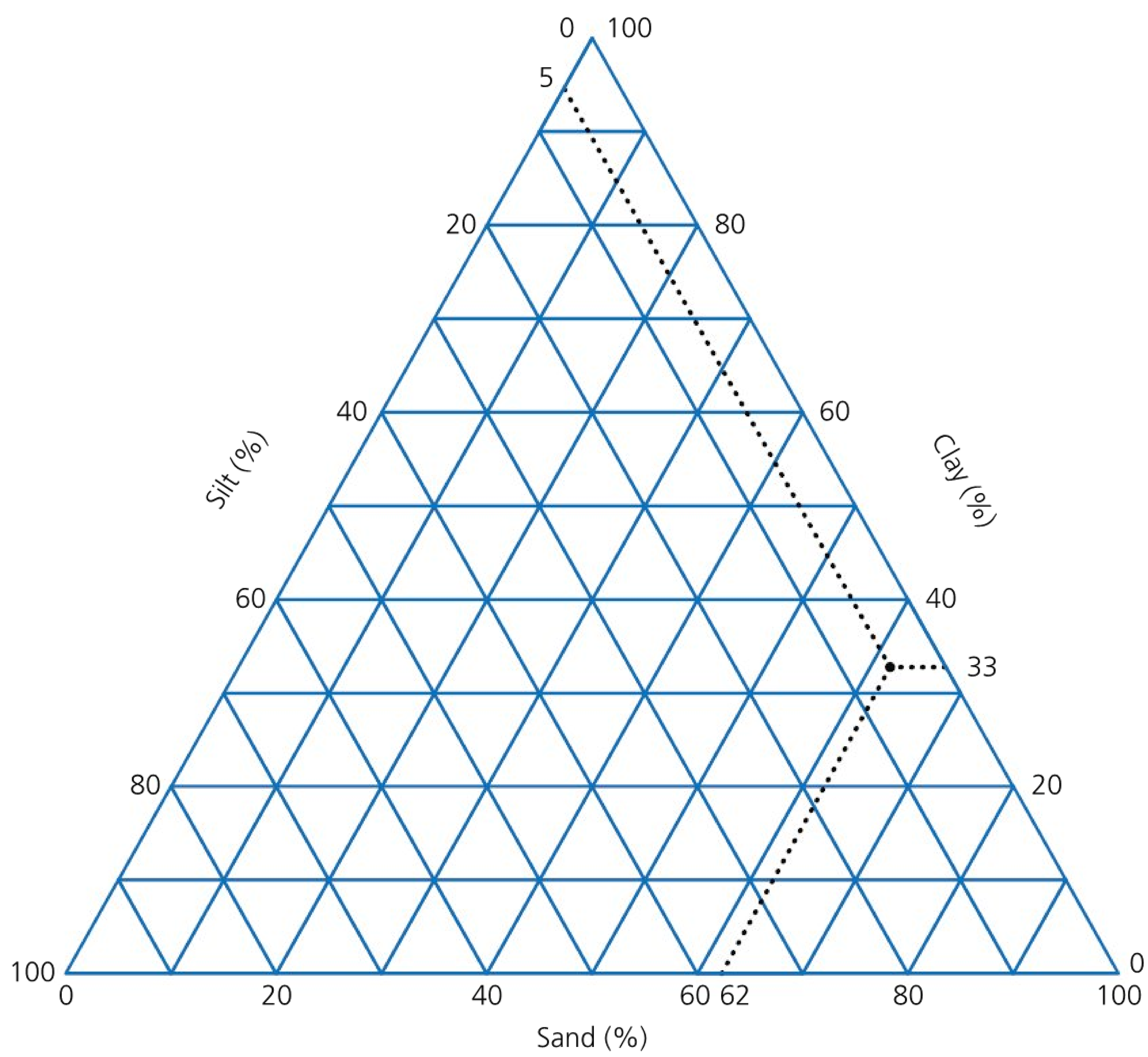
Box-and-whisker plot showing distribution of length data for a selection of maple leaves, indicating minimum, first quartile, median, third quartile, and maximum values

Triangular graphs

These are graphs with three axes which make up an equilateral triangle. They can be used for plotting raw data which can be easily divided into three proportions. They are useful when raw data from several sources are plotted on a single graph. An example of such data are the constituent particles of a soil sample (see table opposite).

Particle	Percentage
Silt	5
Clay	33
Sand	62
	100

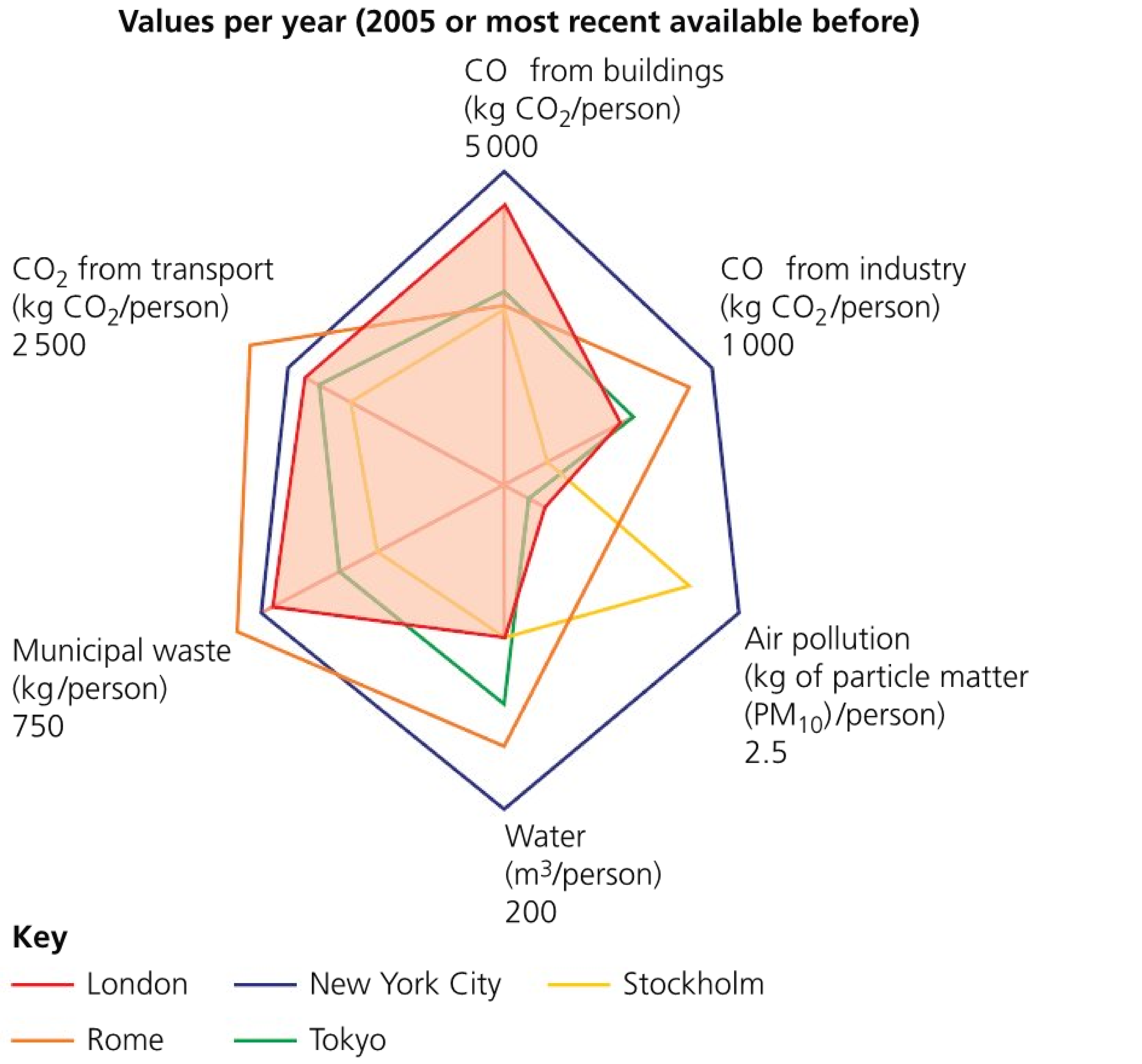
These values have been plotted on the figure below and the dotted lines indicate the way the values are carried across the graph to meet at one point. The position of this point indicates the relative dominance of sand in this particular soil sample. Samples taken from other locations could be analysed for these particles and given a position on the graph.



Triangular graph showing soil composition

Rose diagrams

In a rose diagram, the compass points or other fractions (such as sixths) become different components of the whole. In the diagram below, 'whole' is the environmental impact of cities – the compass points refer to the CO_2 emissions from buildings, industry and transport, and the environmental impact of municipal waste, air pollution and water.



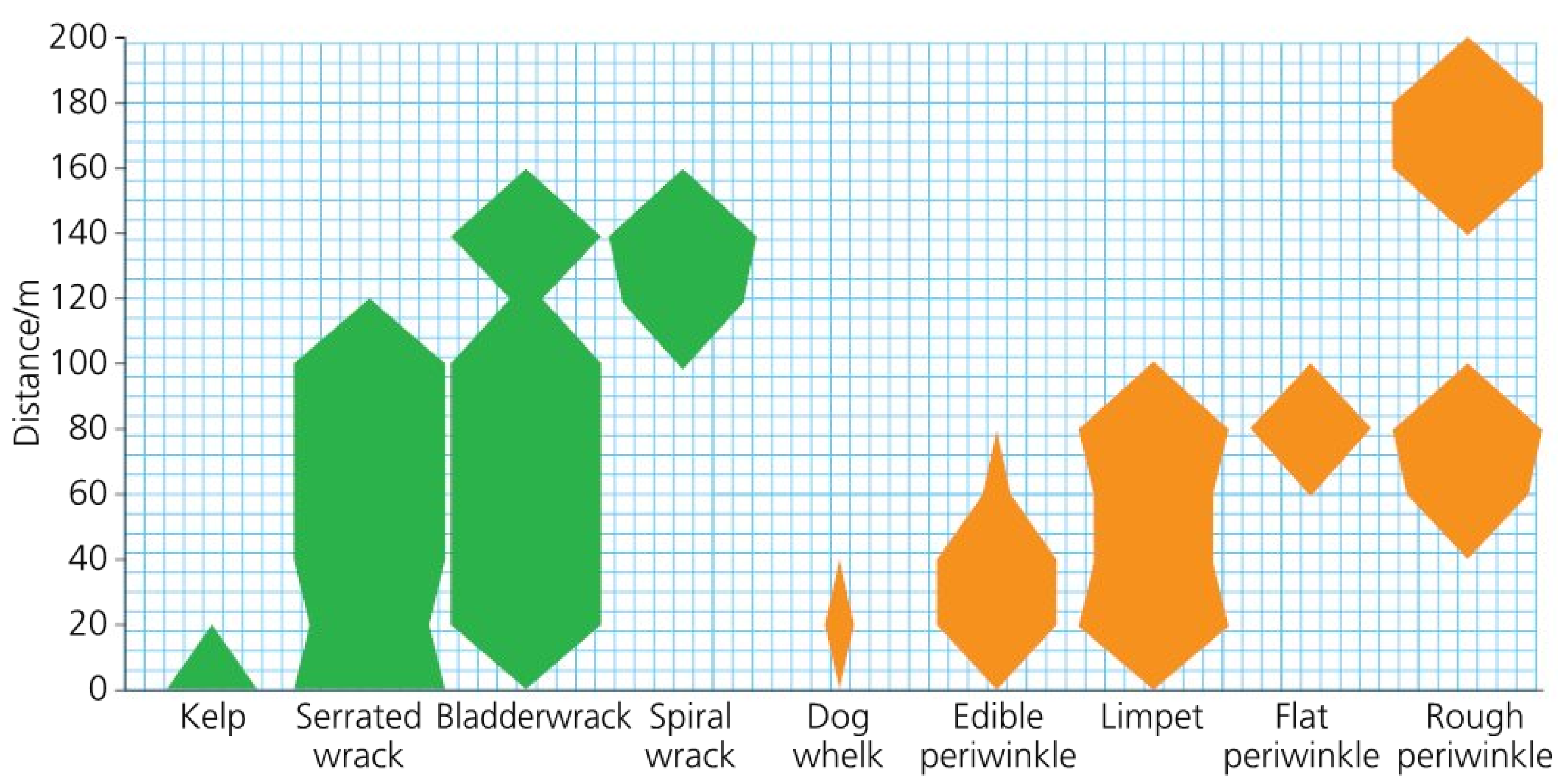
CO_2 emissions from buildings, industry and transport, and the environmental impact of municipal waste, air pollution and water

■ Kite diagrams and the ACFOR scale

If an area is being studied to determine the changes in the distribution of certain animal or plant species along a belt transect, the data collected can be plotted as a kite diagram (see figure below). A kite diagram consists of kites drawn along a baseline. The kites represent the abundances of a species and the wider the kite, the more frequent (abundant) the species is.

Examiner Guidance

If the kite converges into a line then the species is absent at that point on the transect.



The distribution and abundance of organisms along a belt transect, shown in a kite diagram

The actual or relative abundance of a particular species at a particular sample point can be determined by reading the width of the kite from the kite diagram. Kite diagram abundances are sometimes presented using a relative abundance scale known as the ACFOR scale (see table below). The qualitative letter scale is then converted to a numeric scale.

ACFOR scale	Abundance scale
Species absent	0
Rare	1
Occasional	2
Frequent	3
Common	4
Abundant	5

ACFOR scale

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