The human population

The graph of human population growth has not followed the pattern shown in Figure 12.3.5. Since the evolution of humans, no plateau has been reached, and instead the global population continues to rise exponentially. The natural carrying capacity of Earth has been manipulated as humans have found ever more technologically advanced ways to produce food and extract resources from the environment. Humans have also overcome other limiting factors, like disease, through improved medicine, and colonised almost every part of the planet. But over-population has led to poor living conditions and environmental degradation in many parts of the world.

EXAM TIP

You should be able to draw and interpret population growth curves. The curves can be drawn for organisms such as yeast cells in a flask or larger organisms which colonise or inhabit new areas.

TEST YOUR UNDERSTANDING

24 Define carrying capacity.

25 Give an example of a density-independent factor.

26 List two advantages and two disadvantages for a species which lives in a large group.

27 Sketch a growth curve for a population of yeast cells that are growing in a vessel of nutrient fluid.

REFLECTION

Could I summarise the importance of ecological relationships in the survival of organisms? Which ideas would I describe first to a classmate?

Links

- What roles do predators and herbivores have in the transfer of energy and matter? (Chapter 12.2)
- How important is competition in ecological succession? (Chapter 12.4)

12.4 Stability, change and succession in ecosystems

LEARNING OBJECTIVES

In this section you will:

- recognise the factors that maintain stability in an ecosystem
- understand how human actions can lead to a tipping point in ecosystem stability
- define a mesocosm and learn how it can used to study ecosystem sustainability
- learn that a sustainable ecosystem can support itself and recover from outside influences
- understand how farming leads to increased land clearance and increased carbon emissions and loss of biodiversity
- understand the effect of human activity on biochemical cycles and that the release of carbon dioxide is linked to increased global temperatures
- learn that a sustainable ecosystem has high biodiversity
- recognise examples of sustainability in fishing and forestry

> define ecological succession as a predictable change in species structure over time

- understand that a climax community is a state of equilibrium in a stable and functioning community
- learn that primary succession begins in a previously unoccupied area
- discover that human influence can interrupt a succession and lead to a plagioclimax
- Learn that in some communities there is a cyclical succession of communities.

GUIDING QUESTIONS

- How do human activities threaten the sustainability of ecosystems?
- Why is it important for nutrients such as carbon to be recycled?
- To what extent is increased biodiversity important?

12.4.1 Stability, change and succession

Ecosystems will remain stable if they have a sufficient supply of energy, nutrients, genetic diversity and the climate remains stable. A stable ecosystem needs to be resilient to change and this may mean either it has:

- inertia: resistance to change
- resilience: the ability to recover from change
- succession: the replacement of species by another or others.

Ocean ecosystems are very stable because they do not have much variation in productivity from year to year, they are resistant to natural and human disturbance and are resistant to invasion by alien species. Ocean ecosystems have had a stable structure for tens of millions of years. Rainforest ecosystems are also very stable when undisturbed, some are ancient and have been present in their current form for more than 70 million years.

Human interference is threatening some of these ecosystems by upsetting their ability to recover from change. The Amazon rainforest is under threat and it is feared that the removal of trees will lead to a tipping point beyond which the forest cannot recover.

The rapid growth of animal agriculture is the leading cause of deforestation. It is estimated that 70% of the Amazon rainforest has already been destroyed and is now used for pasture and to grow crops. One of the crops grown in the rainforest is soybeans used for animal feed. Tropical deforestation and forest clearing contribute to climate change as carbon emissions are increased. They also cause loss of biodiversity, flooding and soil degradation. Forests are often cleared by burning and this also increases carbon emissions and as well as reducing the capacity of an area to absorb carbon dioxide during photosynthesis.

Some scientists have suggested that to preserve maximum species diversity, humans should change from animal-based agriculture to a greater reliance on plant-based agriculture. Across the world, more land is used to produce feed for farmed animals than to produce plants for human consumption. It is estimated that it takes 20 times less land to feed a person whose diet is mainly plant-based than to feed meat-eaters.

Tipping points in ecosystem stability

Deforestation in the Amazon rainforest has led researchers and scientists to suggest that the forest is losing its resilience and the ability to recover from the effects of droughts, deforestation and climate change. Surveys carried out over more than 30 years using up to 200 satellite images each year show that there are signs of poor growth in more than 75% of the forest and the fear is that trees will die in large areas. The Amazon rainforest holds between 90 and 140 billion tons of carbon and traps carbon dioxide so that it does not contribute to global warming. Some recent studies have shown that parts of it are now emitting more carbon dioxide than can be absorbed. Forest trees also release water vapour into the air as they transpire and this water affects air flow, rainfall and the temperature of the atmosphere. If the cycle of damage continues a tipping point could be reached when the forest is no longer able to recover at all. When this might happen will depend on how we work to prevent it. No one is certain how much rainforest will be sufficient to maintain suitable levels of carbon capture and transpiration but about one fifth of the forest has already been lost compared to pre-industrial times so stopping the removal of trees and preventing deforestation would help. If the critical tipping point is reached the effect on climate change and biodiversity will be very serious. It could be that in less than 50 years the Amazon might become a savannah ecosystem of grassland and trees.

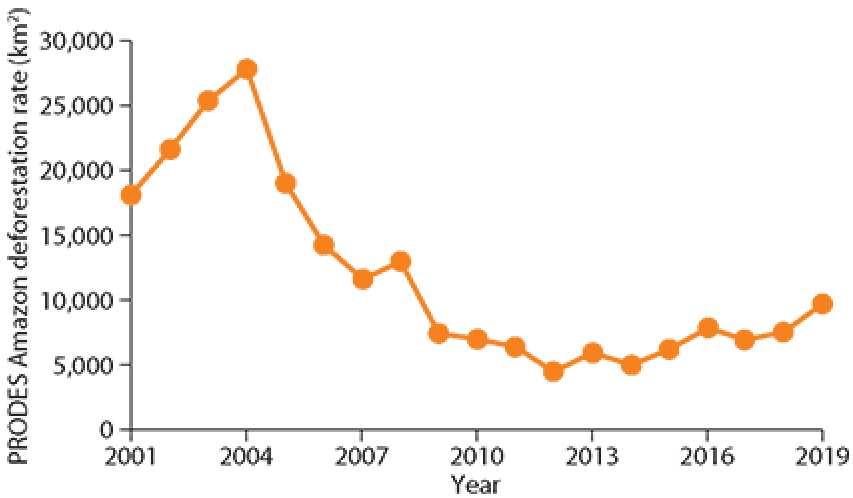

Figure 12.4.1: The deforestation of the Amazon rainforest this century is causing concern

Mesocosms

A **mesocosm** is a small-scale, self-sustaining natural system that can be set up in a laboratory or outdoors to mirror conditions that may occur on a larger scale. We can use a mesocosm to study part of an ecosystem under controlled conditions and draw inferences about how the ecosystem works in the natural environment. Indoor mesocosms, such as simple growth chambers (Figure 12.4.2), provide experimenters with a way to control variables such as temperature and light. In this way the effect of environmental change on species and communities can be predicted.

Open mesocosms have been used outdoors to study the feeding habits of fish when in the presence of different proportions of plankton and competitors.

KEY POINTS

Tipping point is the point beyond which an ecosystem becomes unstable and can no longer recover from change

mesocosms are small-scale enclosed environments that allow part of a natural environment to be observed under controlled conditions.

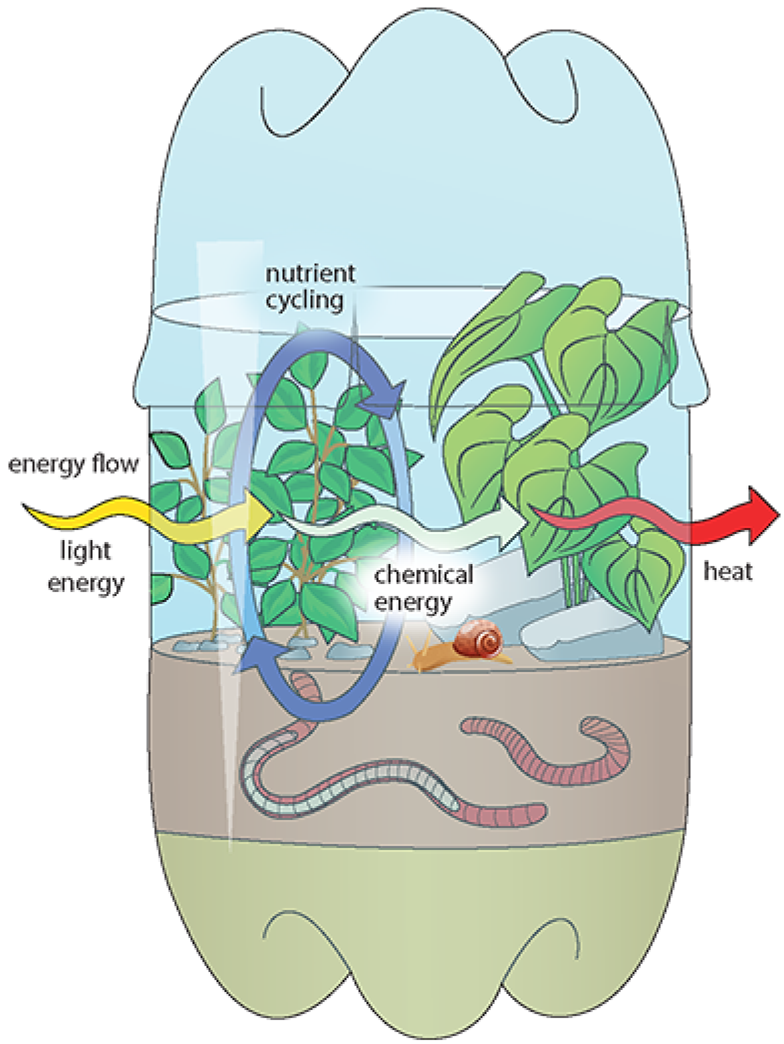

Figure 12.4.2: A simple mesocosm can be set up in a school laboratory.

These mesocosms are usually small enough to allow researchers to monitor important variables and can take account of daily cycles or tides. In shallow ponds, cylinder-shaped mesocosms can be used to assess the effect of temperature change or carbon dioxide levels. Using data from such systems we can attempt to predict the possible effects of environmental change on organisms or communities.

12.4.2 Impact of agriculture

Farming animals and growing crops to feed them uses land. As the human population increases there is an increased need for food. Therefore, more land must be cleared for agriculture. Grassland and fields containing only one crop (monocultures) reduce the natural biodiversity of an ecosystem.

Assessing the sustainability of harvesting resources from natural ecosystems

> **KEY POINT**
>
> sustainability or sustainable yield, depends on the rate of harvesting of a plant or animal being lower that the rate of its replacement.

In forestry, sustainable harvesting is a way of harvesting from a forest that provides a constant supply of wood for human use, but which also protects trees so there are sufficient for harvesting in the future. Sustainably-managed forests meet the needs of wildlife and many support other important features of an ecosystem, such as carbon storage and reducing the risk of flooding.

Here are a few examples of methods used in sustainable **forestry**:

1. **Selective logging** – only harvesting certain trees from the forest instead of removing all of the trees at once. Selective logging helps preserve the balance of the forest and maintain its valuable assets.

2 **Maturity** – All trees have value but that value increases as a tree matures. Allowing young trees time to mature helps protect the long-term value of the forest.

3 **Replanting** – When a tree is harvested a new sapling is planted in its place. This simple method helps ensure the forest is being restored to its original state.

Some examples of the most sustainable hardwood trees are black cherry, willow, aspen, elm, cottonwood, and soft maple trees. These species are used for timber and are fast-growing and absorb large amounts of carbon dioxide.

In **fishing** sustainable yield is the amount of fish that can be caught on a regular basis but still leave sufficient fish of the species to reproduce and maintain the population. Fish stocks need to renew themselves due to losses from both fishing and natural causes. It is important that small fish are allowed to reach maturity and reproduce.

Methods used in sustainable fishing include:

1 Reducing overfishing by legislation and only allow a certain quota of endangered fish species to be caught.

2 Avoiding damage to marine habitats. Some fishing methods – like bottom trawling and dredging – involve scraping heavy machinery along the seafloor and longlines used to catch bluefin tuna can trap birds, turtles and swordfish. These methods can be very destructive to marine habitats.

3 Avoiding bycatch – during fishing, other animals are accidentally caught along with the target species these are known as bycatch. These animals can include dolphins, turtles, sharks and whales, as well as small young fish. In many parts of the world, bycatch are usually thrown back into the sea either dead or dying. Approximately 10% of fish caught worldwide is bycatch.

An example of sustainable fishing involves the Chilean seabass. This fish became a popular restaurant fish in the 1990s. The species lives in the South Pacific and South Atlantic oceans and although fishing in the area is regulated by international agreements, illegal fishing still takes place. At that time, too many fish were caught and the average size of fish declined as poaching and severe overfishing led the species close to extinction. Now, the Marine Stewardship Council (MSC), an international environmental agency based in London, has certified as sustainable a small Chilean sea bass fishery in the South Georgia and South Sandwich Islands near Antarctica. In addition, some sea bass are now farmed in Europe and other areas. Shops and restaurants are encouraged to check that the fish they buy and sell bears the mark of the MSC.

Sustainable agriculture

The aim of sustainable agriculture is to provide the food and plants people need now without damaging the ability of future generations to do the same. For many decades people have used industrial methods of farming with large farms growing monocultures of crops year after year. These farms require large areas of land, often cleared forests, as well as large amounts of fertiliser and pesticides that lead to damage to the soil, water, air and climate. This style of farming degrades the resources it depends on.

To keep farming sustainable we must take care of the land and natural systems that farms rely on. Some of the important things that must be done include:

1 Keeping the soil healthy and preventing erosion

2 Using water resources carefully

3 Keeping water and air pollution to a minimum

4 Storing carbon on farms

5 Protecting farms from extreme weather

6 Encouraging biodiversity

You can read more about aspects of agriculture including **eutrophication**, **biomagnification** and pollution in Section 12.5, as well as human efforts to repair some of the damage that has been caused.

TEST YOUR UNDERSTANDING

28 List 3 factors that are needed to keep an ecosystem stable

29 How can we use the resources of a woodland sustainably?

30 What do the term ‘industrial’ farming and monoculture mean?

KEY POINT

eutrophication is natural or artificial addition of nitrates and phosphate to water, resulting in depletion of the oxygen content.

12.4.3 Impact on biogeochemical cycles

Humans also have important effects on biogeochemical cycles. Figure 12.2.3 in Section 12.2 shows the details of the carbon cycle. Humans interfere with the carbon cycle as we use non-renewable resources such as coal, oil and gas. These non-renewable resources are natural resources that cannot be replaced at a rate that could keep up with human consumption. Non-renewable sources of energy will eventually run out because it takes millions of years for them to be formed. Using these carbon-containing resources also contributes to the release of pollutants such as oxides of sulphur and carbon into the atmosphere.

Renewable resources such as wind energy, solar energy and thermal energy from the ground are abundant and cannot be exhausted as coal and oil will be. Renewable resources are natural resources which are replenished by natural processes, or in recurring cycles, at a pace that keeps up with the rate at which humans use them.

KEY POINT

biogeochemical cycle the way in which an element moves between its biotic and abiotic forms and locations in the biosphere.

Carbon flux

Carbon flux is defined as the flow of carbon from one ‘carbon pool’ to another. The net difference between the carbon removal and the carbon addition can help us understand how we are affecting the carbon cycle. For the Earth’s atmosphere, carbon is removed by plant growth, mineral formation and dissolving in the ocean, while it is added through respiration, burning of fossil fuels and volcanic activity. Scientists monitor carbon flux in order to build up a picture of changes and disturbances in the balance of the carbon cycle (Figure 12.4.3).

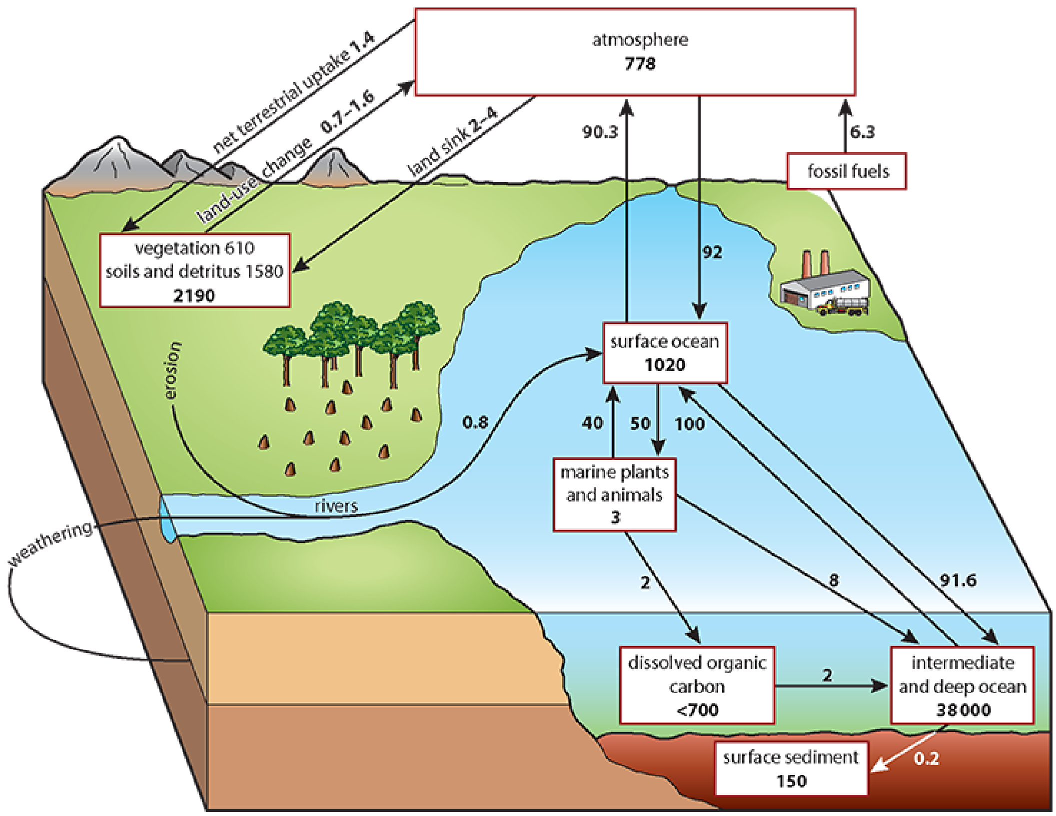

Figure 12.4.3: Diagram showing carbon fluxes in a natural system. Carbon stores (boxes) are shown in gigatonnes (Gt) and carbon fluxes (arrows) are shown in gigatonnes of carbon per year (Gt C·year−1^{-1}).

Carbon dioxide currently forms only 0.04% of the atmospheric gases but it plays a significant part in the **greenhouse effect**. Other greenhouse gases include water vapour, methane, oxides of nitrogen and fluorocarbons.

The human population has increased dramatically in recent history, with a consequent increase in demand for energy in industry, transport and homes. Most of this energy demand has been met by burning fossil fuels, mainly oil, coal and gas. Burning fossil fuels releases both carbon dioxide and oxides of nitrogen. This activity has raised the concentration of carbon dioxide in the Earth's atmosphere significantly since the mid-1800s, a period which has coincided with increasing industrialisation (Figure 12.4.4). Carbon dioxide concentration has risen by more than 20% since 1959 (Figures 12.4.5 and 12.4.6).

In the tropical regions of the world huge rainforests trap carbon dioxide through photosynthesis and have been important in maintaining the low level of atmospheric carbon dioxide. Humans have upset this balance by removing vast areas of forest for agriculture and timber production.

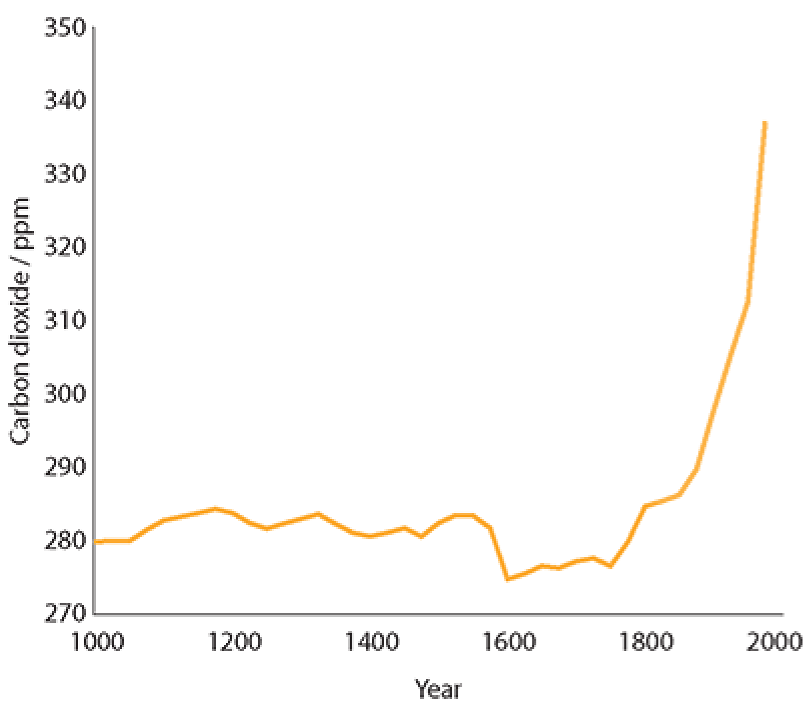

Figure 12.4.4: Graph to show the increase in carbon dioxide concentration in the atmosphere since the Industrial Revolution in the mid-1800s.

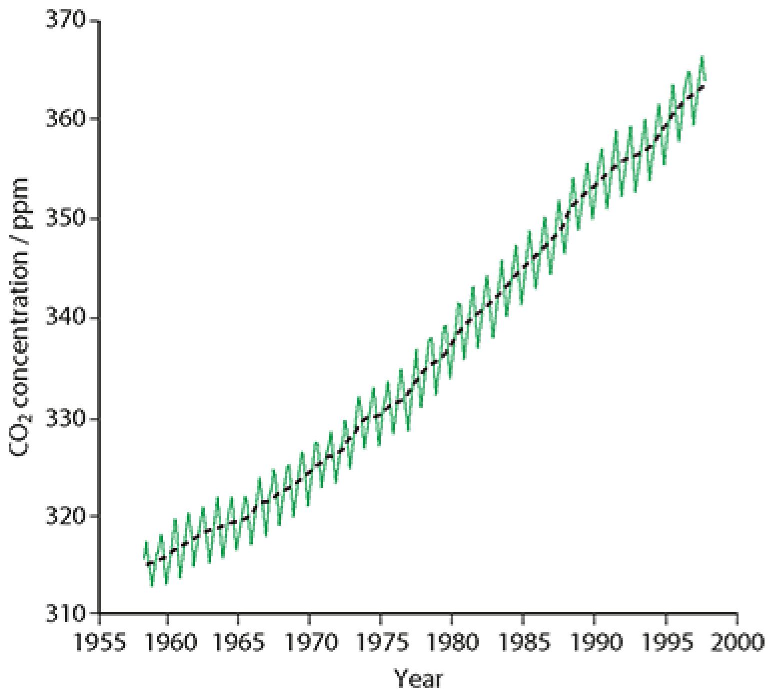

Figure 12.4.5: Atmospheric carbon dioxide concentration measured at monthly intervals in Hawaii.

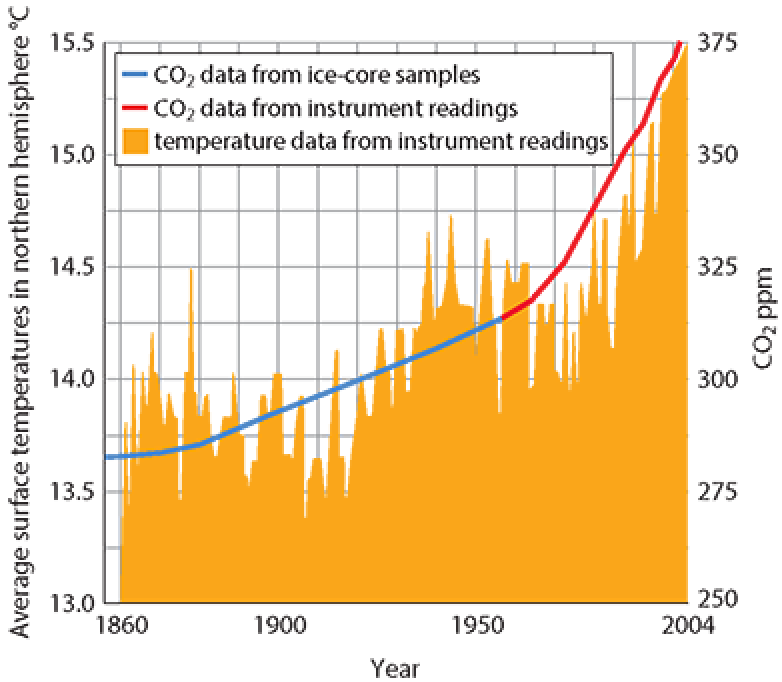

Figure 12.4.6: Graph showing carbon dioxide and temperature data from different sources. There is a correlation between rising carbon dioxide levels and global temperature which is evidence of global warming.

Forest destruction has multiple effects, but the most important ones for the atmosphere are the loss of carbon dioxide uptake by photosynthesis and the increase in carbon dioxide released from the rotting or burned vegetation.

The increase in carbon dioxide in the atmosphere has been linked to increased global temperatures. The Earth is kept warmer by the presence of carbon dioxide, water vapour and other gases in the atmosphere. These gases are known as greenhouse gases. Radiation of longer wavelengths from the Sun strikes the Earth and is reflected from its surface. Up to 85% of the radiation is reabsorbed by greenhouse gases before it has passed back into space. Energy is re-emitted towards the Earth so that the greenhouse gases keep the heat in the atmosphere. There is a strong correlation between the concentration of carbon dioxide in the atmosphere and global temperature (Figure 12.4.6). Data on the carbon dioxide concentration in the atmosphere are collected from instruments at monitoring points all over the world. They are also taken from the study of ice cores removed from deep below the Earth's surface. Ice cores have been used since the 1950s to study our atmosphere and climate. Ice cores have been drilled from ice sheets worldwide, but especially from those in Greenland and Antarctica. Bubbles in the frozen ice preserve samples of the world's ancient atmosphere. These can be analysed to show how atmospheric carbon dioxide levels in the atmosphere have changed over the last 10 000 years (Section 12.5).

The size of the circles and arrows is proportional to the amount of nutrients stored or transferred.

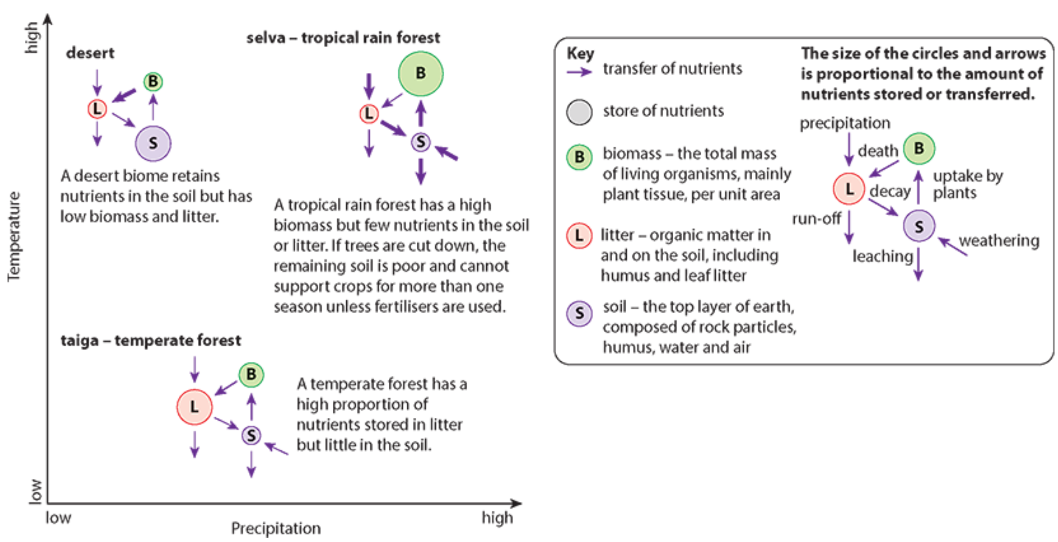

Figure 12.4.7: The model of nutrient cycling developed by Gersmehl.

NATURE OF SCIENCE

Using models to represent the natural world – Gersmehl diagrams

The United Nations Intergovernmental Science-In 1976, the geographer and scientist P.F. Gersmehl developed a model of nutrient cycling to highlight differences between ecosystems. His diagrams (Figure 12.4.7) show how nutrients are transferred and stored between three different parts of an ecosystem: the leaf litter (dead and decomposing leaves), biomass of organisms and the soil. As nutrients cycle in an ecosystem, there are interactions between the atmosphere and soil, and many food chains are involved. Nutrient cycles are different in different ecosystems and the rate of nutrient transfer is dependent on the amount of moisture, heat and vegetation, and the length of the growing season. Diagrams can be drawn for different ecosystems and provide insights into systems that have high levels of nutrients in the soil or a large biomass of organisms.

- A desert biome retains nutrients in the soil but has low biomass and litter.
- A tropical rain forest has a high biomass but few nutrients in the soil or litter. If trees are cut down, the remaining soil is poor and cannot support crops for more than one season unless fertilisers are used.
- A temperate forest has a high proportion of nutrients stored in litter but little in the soil.

12.4.4 The processes of succession

Ecological succession is the process of change that occurs in communities in a particular area over a period of time. Eventually the appearance of the whole area develops and changes. Succession involves interactions between both the biotic (living) and abiotic (non-living) components of the area. Abiotic factors limit the distribution of organisms and the organisms have an effect on the abiotic factors.

If an area of land is left bare as a result of an event such as a fire or land clearance, early 'pioneer' communities modify the physical environment, which, in turn, modifies the biotic community. This enables more species to move in and modify the physical environment still more, and so on until a stable situation is reached. The different stages of succession are known as seral stages and the final stable community, which remains unless there is further disturbance, is called a climax community.

KEY POINT

ecological succession is the predictable sequence of different communities that appear in a given habitat over a period of time.

Figure 12.4.8: Surtsey Island was formed in 1963 and has been studied since that time. A primary succession began as lichens and mosses began to colonise the bare volcanic rock.

A primary succession begins when an area of bare ground or rock, with no existing soil, is colonised for the first time. It may take place where a glacier is retreating and leaving a place where no organisms have existed before. Two examples of primary succession have been studied over many years by ecologists. These are an area on the Indonesian island of Krakatau that was left bare when the volcano Krakatoa erupted in 1883, and the newly formed volcanic island of Surtsey off the coast of Iceland, which formed in 1963 (Figure 12.4.8).

The first organisms to colonise bare rock are bacteria, lichens and mosses, which can settle on the rock surface. Lichens gradually break up the rocks and use dissolved minerals for growth. As lichens die they decompose, leaving debris, which begins the formation of humus (fragments of organic matter) and soil. Low-growing lichens and mosses modify the environment sufficiently for seeds of grasses and small shrubs to start growing and these plants modify the land still further. A deeper layer of soil develops as plants die and decompose, and this soil can hold more moisture and contains more organic matter. Later, fast-growing trees will begin to grow and, as they extend their roots, the soil is bound together and protected from erosion. Eventually these trees will be replaced by slower-growing species, which form a climax community, usually after a period of about 100–200 years.

Secondary succession occurs where an ecosystem has already existed. In this case succession is initiated by a change in conditions, perhaps a land clearance, a fire or a landslip. An ecosystem has been established in the past but is replaced as conditions have changed. Soil is already present so secondary succession is usually much quicker than primary succession and a variety of plants such as annual grasses and low-growing perennials (plants that live for more than 2 years) can colonise rapidly. Shrubs and trees follow and eventually a stable climax community is established (Figure 12.4.9). Changes still take place when a climax community is present but they are slow and the system is more stable and resistant to change. In the later stages of succession, there are more consumers present, with more complex feeding interactions and food webs developing.

Stability and climax communities

A **climax community** can tolerate the existing environmental conditions and it has a wide diversity of different species. This type of sustainable ecosystem can support itself and provide requirements such as inorganic nutrients without external influences. A climax community has the potential to remain stable and self-sustaining for a long period of time. There needs to be enough sunlight to provide energy for the autotrophs to photosynthesise, and the community itself must be able to maintain the recycling of inorganic materials within the abiotic environment. The climax community will remain stable as long as there are no adverse interferences from outside.

KEY POINTS

climax community is the stable stage at the end of a succession of communities in an ecosystem.

primary succession is colonisation of an area of bare ground or rock.

secondary succession is colonisation of an area of land that has been cleared (e.g. by a fire or landslide) and where soil is already present.

A typical succession in the northern hemisphere might be:

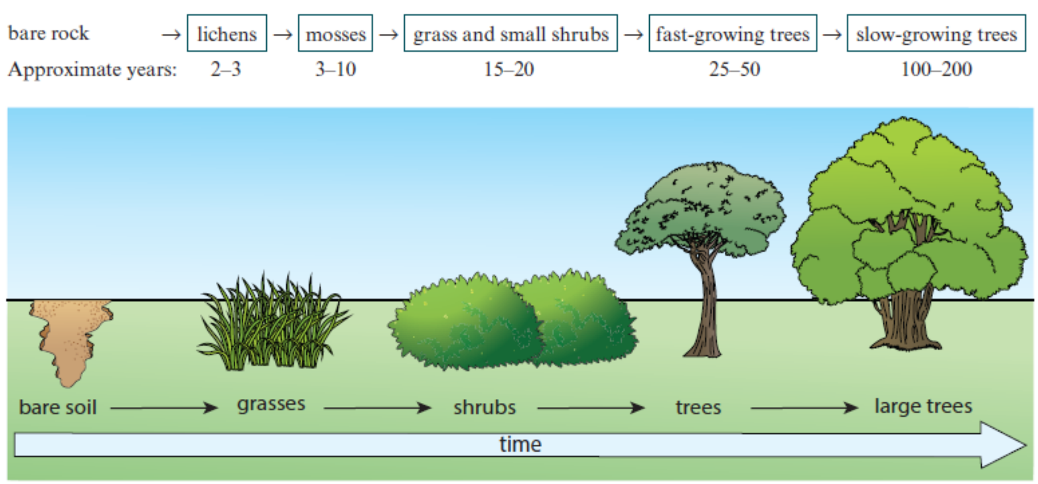

Figure 12.4.9: Undisturbed, bare land will gradually change from grassland to shrubland and then become home to small

short-lived trees. Eventually larger, slow-growing trees will grow, which form mature woodland.

Climax communities are said to be in a state of equilibrium or a ‘steady state’ because the organisms that live there have adapted to their environment and succession is no longer taking place. The community has achieved a high level of biodiversity and is not changing. Catastrophic natural events, such as flooding, wildfires, hurricanes or earthquakes, and human interference are two factors that can disrupt otherwise stable ecosystems. It is important to remember that sustainable, stable systems are vital for the continued survival of all species, including our own.

The type of stable climax community that emerges following a succession depends on the local climate. Rainfall and temperature are the two most important factors that determine the communities in a stable ecosystem. Figure 12.4.10 shows a climograph, which is a diagram that relates the type of ecosystem to conditions of temperature and rainfall in the region. A climograph can be used to predict the type of stable ecosystem that will emerge in an area.

Cyclical succession

Cyclical succession is a pattern that can been seen in a stable area where there are no specific disturbances. Vegetation may change as a small number of plant species replace one another in a regular cycle (Figure 12.4.11) as the resources available change over time.

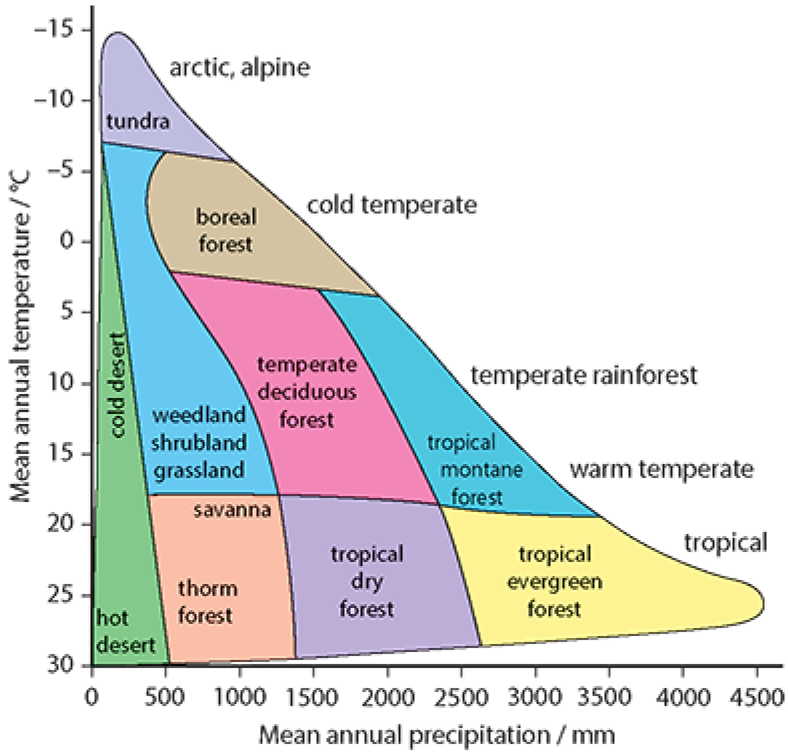

Figure 12.4.10: A climograph shows the differences in vegetation, and therefore type of ecosystem, in different climatic regions.

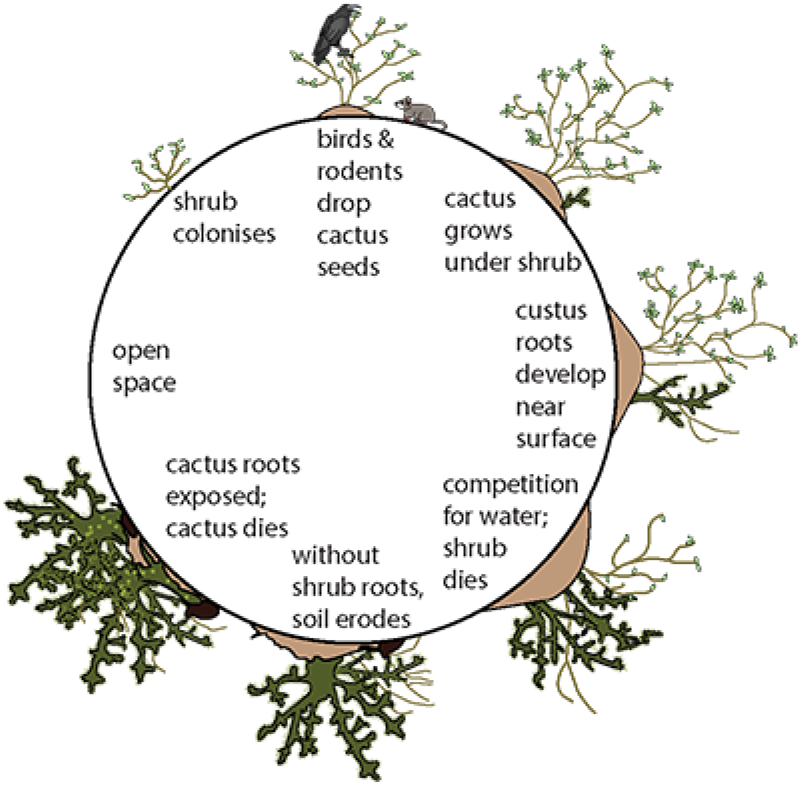

Figure 12.4.11: Cactus and shrub replace each other in an example of cyclical succession.

THEORY OF KNOWLEDGE

Complexity theory and communities

Complexity theory is a theory that tries to describe and explain the properties of complicated systems, not only in the biological world, but also in our social world. Examples of such systems include neural networks, community ecosystems and business organisations. Systems like these have emergent properties that are a result of the ability of individual parts of the system to organise themselves. For example, consider the millions of people who interact to create a society, or the thousands of species that interact to make up a climax community in an ecosystem. If you examine a single animal or a single plant, or just one person, you could not tell whether it would be able to do things and operate with others to create the community in which they all exist. Each system or community is a product of the interactions between the individuals that live in it. Without those individuals there could not be a complex community. Complexity theory takes a holistic approach to the natural world and does not separate the components and processes in a system. This is unlike the reductionist approach, which proposes that we explain a system by breaking it down into its individual parts.

We cannot predict with any certainty how a complex system will evolve, and this unpredictability underlines the complexity of life.

To consider:

1 To what extent do you think a climax community provides an example to support complexity theory?

2 Is it ever possible to predict the effect of changes to the climate or other abiotic factors on a climax community?

TEST YOUR UNDERSTANDING

31 List three ways in which human activities can lead to the formation of a plagioclimax.

32 Outline the problems caused by the introduction of an alien species.

33 Summarise the problems caused by microplastics in the ocean.

12.5 The biodiversity crisis

LEARNING OBJECTIVES

In this section you will:

- recall that biodiversity is the variety of life in all forms and can relate to ecosystems, species or genetics
- understand that there are more species on earth today than in the past
- learn that human causes are responsible for the extinction of many species today
- recognise that diversity is lost due to loss of habitats, overexploitation of resources and agriculture. recall the reasons for the loss of species including giant moas, caribbean monk seals.
- recognise the causes of ecosystem loss due to agriculture, including southeast asian forests understand the evidence for biodiversity crisis and its causes.
- recognise that conservation of biodiversity requires many different measures including nature reserves, rewilding and reclamation of degraded ecosystems
- understand why some species are selected for conservation efforts while others are not in the EDGE of existence programme
- recognise that human activities disrupt the nitrogen cycle understand the impact of biomagnification.

- recognise that non-renewable resources are finite while renewable resources are abundant
- learn that introduced species can become invasive and reduce biodiversity
- recognise that release of pollutants can increase levels of these substances in ecosystems

GUIDING QUESTIONS

- What are the factors that are causing the 6th mass extinction?
- How can we minimize the loss of biodiversity?

12.5.1 Conservation of biodiversity

The importance of diversity

Ecosystem diversity is the number of ecological **niches** or range of different habitats that are present per unit area of a **biome**, **ecosystem** or **community**. If habitat diversity is conserved, this usually leads to the conservation of both species and genetic material.

There are three main ways to study diversity:

Ecosystem diversity

The range of different habits in an ecosystem is one of the most important factors to consider in a study of the conservation of biodiversity. To assess habitat diversity, ecologists study the variety of niches that a habitat contains. A rainforest has a high diversity of habitats which include the canopy, the soil and pools of standing water, so that there are many ecological niches present. On the other hand, a desert has little habitat diversity, simply a sandy terrain and a few plants, so it provides few ecological niches. An increase in habitat diversity is always likely to lead to an increase in both species diversity and genetic diversity.

Species diversity

Species diversity is a measure of the variety of species in a given area; it is quantified by measuring both the number of species present (species richness) and their relative abundance. (You can read about the Simpson diversity index which is one of the ways used to quantify diversity in Chapter 11.) A complex ecosystem like a rainforest contains a wide variety of species which are likely to be abundant, so the species diversity is high.

Genetic Diversity

Genetic diversity is the range of genetic material present in a population. It follows that where more species and more individuals of a species are present, the range of genetic material present will also be greater. Genetic diversity is recognised by a large gene pool. The gene pool is the number of variations of the same gene that are present in the DNA of a particular species. A large gene pool is the sign of a healthy population with high genetic variability. A small gene pool will indicate low genetic diversity.

Comparing current and past levels of species and diversity

Scientists have estimated that there are around 8.7 million species of plants and animals in existence today. However, only around 1.2 million species have been identified and described so far, most of these are insects.

There is no accurate figure for the number of species alive on Earth today. Organisms which are found are described by scientists and recorded or stored in institutions such as the Natural History Museum in London and the collections of other research organisations such as **CITES** (**Convention on International Trade in Endangered Species of Wild Fauna and Flora**) which records endangered species. Estimates of the number of species that have never been found or named vary widely. An accepted view is that over 1.75 million species have been described but that there may be more than 10 million actually alive (Table 12.5.1).

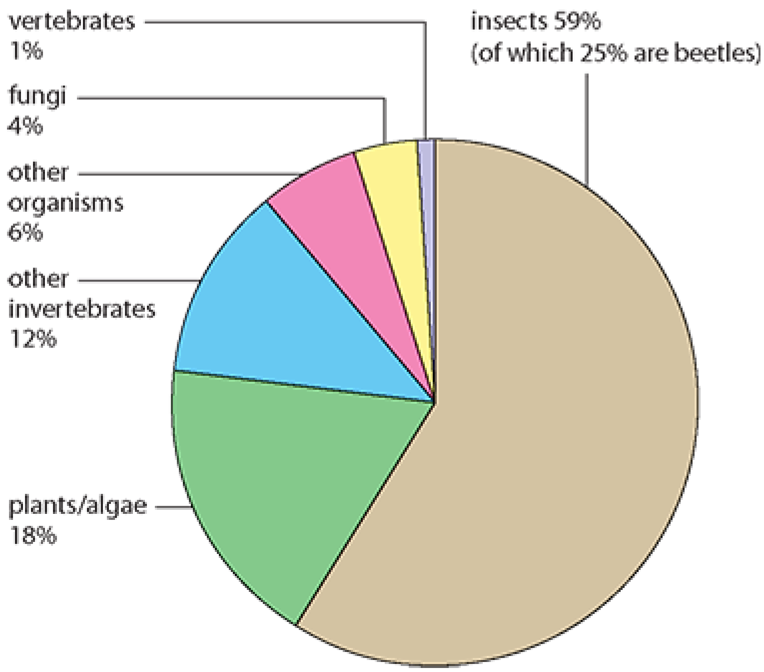

Figure 12.5.1: The largest group of organisms that have been identified is the insects and 25% of the named species are beetles.

Kingdom	Number of species
bacteria	4 000
fungi	72 000
protoctists (algae and protozoa)	80 000
plants	270 000
animals (vertebrates)	52 000
animals (invertebrates)	1 272 000
total number described	1 750 000
possible number of unknown species	14 000 000

Table 12.5.1: ***Estimates of total numbers of species***. Some scientists think that the figure may be substantially higher than

this.

Adapted from: UNEP–WCMC (2000). Global Biodiversity: Earth's living resources in the 21st century. *Cambridge, World Conservation Press*

Most estimates of the number of species are based on mathematical models. These models depend on the amount of data which is available to be put into them. Many habitats and groups of species are under-recorded because it is difficult to reach them. There may also be insufficient funding for expeditions and scientific research and, in some cases, there is disagreement about the classification of certain groups.

Species extinction caused by humans

KEY POINT

mass extinctions are periods in the Earth's history when very large numbers (more than 75%) of species die out simultaneously or within a very short period of geological time.

Mass extinctions result in an **Earth system succession**, which occurs when significant global environmental or biotic change takes place and pushes the biosphere and geosphere out of equilibrium. Species and ecosystems do evolve again after a mass extinction. As they do so they change the world's biogeochemical cycles, as well as species and ecosystems, in a process that takes many thousands or millions of years. Earth system succession goes some way to explaining the patterns of evolutionary and environmental change and the organisms that are present in the fossil record.

The most severe extinction occurred at the end of the Permian period 250 million years ago when 96% of all species were wiped out. There are about 12 million different species present on Earth today but this represents only about 1% of the total number of species that have lived. Since the beginning of life on Earth there have been several mass extinctions.

Movements of the continents, huge volcanic eruptions, drought and ice ages, and also the impact of huge meteorites on the surface of the Earth, have all caused mass extinctions. Events like these cause such massive changes in climate or physical features of the Earth that, as well as destroying species, they present new challenges to the survivors and lead to new evolutionary paths. An increase in biodiversity may be the long-term consequence of mass extinctions.

Causes of mass extinctions

The average time between mass extinctions has been about 100 million years. Palaeontologists, who study fossils, have recorded five mass extinction events throughout Earth's history (Figure 12.5.2).

1. **Drop in sea level** – The first great mass extinction event took place about 440 million years ago (mya). Extinction was probably caused by a drop in sea levels as glaciers formed, followed by rising sea levels as they melted.

2. **Cause unknown** – About 360 mya, Earth experienced the second mass extinction event. Around 20% of all families (50% of all genera) became extinct.

3. **Asteroid or volcano** – Around 250 mya, a third mass extinction occurred. It could have been due to either an asteroid colliding with the Earth or a flood of volcanic

material escaping from an area in what is now eastern Russia.

4 **Undersea volcanic eruption** – About 200 mya. An extinction was probably caused by a flood of lava escaping from a volcano in the Atlantic Ocean.

5 **Asteroid or comet collision** – The mass extinction of 65 million years ago is famously associated with the extinction of the dinosaurs. Almost no large land animals survived. Details of the five mass extinctions are summarised in Table 12.5.2.

Human activities: the sixth mass extinction

Today, populations of many species are in decline and some scientists have warned that Earth is on the brink of another mass extinction. Unlike the five previous mass extinctions, the sixth is related to human activities and is happening at a much faster rate. Current species extinction rates are hundreds or thousands of times faster than the normal background rates that occurred in the last tens of millions of years. A recent United Nations report on biodiversity and ecosystems estimated that a quarter of all species on Earth now face extinction. The loss of a species is permanent and each one has a role in the living systems on which we all depend. The huge losses that we are observing are being caused, directly or indirectly, by human activities. The two main reasons for this are the way that humans have spread and occupied territories all over the world, and the development of agriculture in the last 10 000 years. At that time there were about 1 million people in the world but today there are 7.7 billion. The human population is still growing and with more people, more land has been taken and more species exploited. Species do not have the chance to move to new areas, and pollution and climate change have added to the destruction of their ecosystems. Species have been unable to adapt because of the speed of changes on Earth, largely caused by humans. Organisms do not have the chance to move to new areas, and pollution and climate change (Section 12.6) have added to the destruction of their ecosystems.

Extinction	**Approximatetime/mya**	**Geological era**	**Loss of species (estimate)**
1	439	Ordovician	25% families
2	364	Late Devonian	20% families
3	251	Permian–Triassic	55% families
4	199–214	End-Triassic	25% families
5	65	Cretaceous–Tertiary	17% families (all dinosaurs)

Table 12.5.2: The five mass extinctions that have been identified.

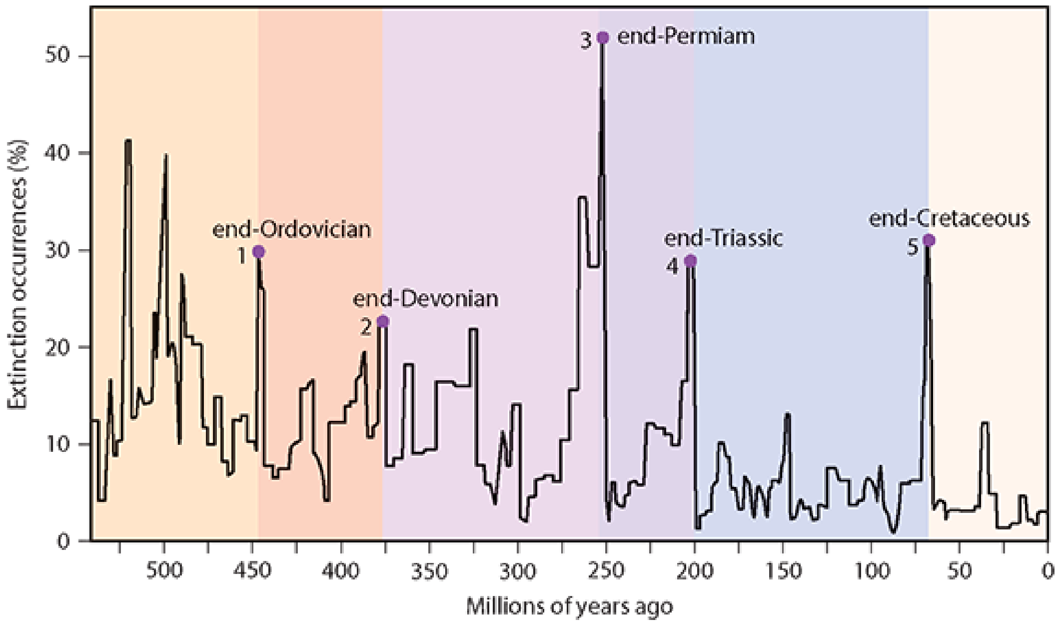

Figure 12.5.2: The five mass extinctions on Earth.

Extinction is defined as the point when a species ceases to exist or the last known individual of the species dies. Palaeontologists characterise mass extinctions as times when the Earth loses more than three-quarters of its species in a geologically short interval. The background extinction rate is the natural extinction rate of all species. Scientists estimate that it should be about one species per million per year or up to 100 species per year. Just over 5000 mammal species are known to be alive today, so the background extinction rate should be one per 200 years, but in fact about 90 mammals have become extinct in the last 400 years and 170 are listed as critically endangered. This evidence suggests that the current extinction rate is far higher than it should be and, in many cases, it is humans who are causing the extinctions. But since the total number of species known to science is only a small fraction of the estimated total, estimates of extinction rates can also vary. The current rates are probably between 100 and 10,000 times greater than the background rates. Humans have already wiped out many species including large mammals and flightless birds such as the dodo.

Causes and consequences of the current sixth mass extinction

The key factors responsible for the current mass extinction are:

- loss of habitat to agriculture, cities, roads and industry
- overexploitation of resources such as timber and fish, and in hunting and agriculture
- pollution and climate change
- introduction of alien species as humans move species from one continent to another.

The north island giant moa (*Dinomis novaezealandiae*) is an example of a species which has become extinct due to human activities. For millions of years, nine species of large, flightless moas thrived in New Zealand (Figure 12.5.3). Then, about 600 years ago, they abruptly became extinct. Their disappearance coincided with the arrival of the first humans on the islands in the late 13th century. Scientists have speculated that the moas were hunted to extinction by these Polynesian settlers who killed them for food. Recent DNA studies of the bones of 281 moas from four species determined that the birds were healthy and that their populations were increasing before the arrival of settlers. Their genes did not indicate that they were likely to face extinction. The birds disappeared shortly after humans arrived in their habitats and were probably exterminated by overhunting as humans took what they needed to survive.

The extinction of many other species of megafauna (giant animals including mammoths, mastodons, and moas) began between 9000 and 13,000 years ago, when human populations began to spread around the world.

Figure 12.5.3: The Giant moa can only be seen in old drawings and engravings

Another more recent extinction directly linked to human activity is the Caribbean monk seal (*Neomonachus tropicalis*) which originally inhabited the beaches and reefs of the Caribbean. The last seal was seen in 1952 at Serranilla Bank, between Nicaragua and Jamaica. In the early 17th century there were at least 13 breeding colonies with a total population of more than a quarter of a million individuals. When early explorers arrived in the region, the seals were a curiosity and a source of food. Records show that Christopher Columbus ordered 8 'sea-wolves' to be killed in 1494 and the Spanish explorer de Leon killed 14 seals in 1512. European hunters often visited the area in the 17th century, and the scientist Hans Sloane in 1707 wrote that local fishermen would kill 100 in one night to fuel their oil lamps. Later settlers who had established plantations sent hunters to kill hundreds of seals for oil to grease their machinery. The Caribbean monk seal is the only seal species which has become extinct in modern times. The reason for its extinction is due to human actions. Seals were slaughtered in large numbers not only by European hunters, local fishermen and plantation settlers but also by scientists from the 17th to the 19th centuries.

Today, overhunting, climate change, pollution and loss of habitat are the main factors which are threatening populations of species all over the world. Some examples of large vertebrate species that are at risk include the Amur leopard, black rhino, cross river gorilla, hawksbill turtle, Javan rhino, leatherback turtle, mountain gorilla, and south China tiger, but many smaller species and invertebrates are at risk too.

In the high altitudes of South America, the golden toad (Fig 12.5.4) has become extinct because of pollution, global warming and fungal infections and many other species of amphibians have been lost. They are very temperature sensitive and are also affected by the toxins in their water sources. and the reduction of insect populations due to pollution also reduces the food available for the toads.

Figure 12.5.4: This is the last photograph of the Golden toad before it became extinct. It was taken in Costa Rica in 1978

Causes of ecosystem loss

Human activity has had a significant effect on natural ecosystems throughout the world. Habitat degradation and fragmentation reduces the number of places for organisms to live. Human activities have changed land with building projects and land clearance. Agriculture, particularly intensive farming reduces diversity because monocultures replace more complex systems or remove them completely. One clear example of the effect of intensive farming can be seen in the mixed dipterocarp forest Southeast Asia (Figure 12.5.5). This forest used to be the dominant forest type, it has a complex but uniform structure with a dense, multi-storied trees with an uneven canopy.

Southeast Asia is a hotspot of biodiversity with many unique species, but the region is also one of the most threatened. Ecosystems are threatened by factors which are likely to lead to the extinction of many species. Deforestation rates in Southeast Asia are some of the highest in the world, it also has the highest rate of mining in the tropics and the greatest number of hydropower dams under construction.

Tree-plantations and deforestation are two of the most immediate threats, and some countries such as the Philippines and parts of Indonesia have already lost over half their native forests. Predictions suggest that as much as 98% could be lost in some places in the next 10 years. Mining is also a threat, as the region exports large quantities of limestone and minerals. Biodiversity suffers directly because land is used for mines, but indirectly as roads are built through habitats and land is polluted by heavy metals.

Figure 12.5.5: Unspoilt mixed dipterocarp forest in Borneo

Figure 12.5.6: Oil palm plantations in Borneo appear as bright green areas with only small areas the natural forest remaining

Large-scale tree plantations have had the greatest impact on the forests. Oil-palm trees, rubber trees and trees for wood pulp and biofuels have replaced native forests. Oil-palm was first planted in around 1970, yet by 2011, exports had reached 30 million tonnes annually from Indonesia and 20 million tonnes from Malaysia. These two countries export almost 86% of global oil-palm.

As tropical forests are cleared carbon is released into the atmosphere as carbon dioxide; estimates suggest that tropical deforestation accounts for about 10 percent of total global warming emissions. But the biggest impact of palm oil production is on biodiversity and the large-scale devastation of habitats for endangered species such as Asian rhinos, elephants, tigers and orangutans.

There are many other examples of human interference causing loss of ecosystems. You might like to study the effect of major building projects such as the Yellow River Dam in China or the threat to biodiversity as a result of the introduction of non-native fish to the rivers and lakes in Madagascar which have led to serious reductions in the biodiversity on the island.

NATURE OF SCIENCE

Evidence for a biodiversity crisis

The United Nations Intergovernmental Science-Policy Platform on biodiversity and ecosystems (IPBES) carries out regular assessments of biodiversity and ecosystems throughout the world. They have published eight assessments so far and most suggest that biodiversity is being badly affected in most regions. Their estimates are that one million plant and animal species face extinction. Such surveys must take into account not only the number of species present but also species richness and evenness in a given ecosystem.

The International Union for Conservation of Nature and Natural Resources (IUCN) is an organisation dedicated to nature conservation. It has assessed those species which are most at risk based on data relating to critically endangered, endangered and vulnerable species. The IUCN estimations are that 30% of amphibians and 28% of reptiles are seriously under threat and many smaller, invertebrate organisms may become extinct before they have even been discovered and given names.

Surveys by international organisations are invaluable as the data is collected using standardized methods and can be checked by other scientists and experts. And repeated at regular intervals to monitor changing situations. But the input of ‘citizen scientists’ who follow the appearance of bird species in the local area or the diversity of insects on their land is also needed. Data bases can collect such information and feed it into larger nationwide surveys.

To consider:

1. How are the methods used by international organization likely to differ from those you might use to report on local biodiversity?
2. Why is it important that scientific evidence is checked and published?

12.5.2 Causes of the Biodiversity crisis

The current biodiversity crisis has largely been caused by humans. Our population has increased from around 3 billion in 1960 to 8 billion in 2022. More people require more land to live on and to grow food so habitat destruction and species exploitation have both increased. In section 12.5.1 we considered the effect of habitat destruction for agriculture but there are many other factors that have caused the current biodiversity crisis.

Pollutants released by humans

People release many kinds of pollution into the environment. Pesticides, industrial chemicals, waste from mining and agriculture, and gases from combustion are some examples. All of these pollutants find their way into ecosystems that may be thousands of kilometres away. One serious and non-biodegradable pollutant is plastic.

Over recent years the production and use of plastics has increased enormously. It is estimated that over 250 million tonnes of plastic are used annually and that making plastic items uses approximately 8% of the world's annual oil production. Plastic litter degrades very slowly: a plastic bottle will take 450 years to break down and so plastic waste builds up on land and in the oceans. Plastic makes up between 60 and 80% of marine debris and as much as 90% of floating debris.

Macroplastic debris is defined as plastic fragments which are greater than 1 mm across, while microplastic debris has fragments that are less than 1 mm. Macroplastics include items such as plastic bottles and bags, detergent containers and food wrapping. These items accumulate in marine habitats all over the world and may remain for centuries. Microplastics from PVC, polyester, acrylic and polyamide account for more than 65% of marine debris. Researchers have traced much of the microplastic back to synthetic clothes, which can release up to 2000 tiny fibres per garment every time they are washed.

Both types of plastic are ingested by marine organisms, which mistake them for food. This plastic may enter the food chain as residues of the plastic accumulate in organisms' cells. An animal whose stomach is full of plastic fragments feels full and may stop feeding so that it starves to death.

Figure 12.5.7: Dead Laysan albatross chick with a stomach full of plastic debris.

The Laysan albatross lives on Midway Atoll in the North Pacific Ocean, thousands of kilometres from both mainland Asia and North America. Albatrosses skim the water surface to feed and pick up plastic as they do so. Adults feed the plastic to their chicks and while adults are able to regurgitate some plastic, the chicks cannot and can be killed by its effects. As well as making the chick feel falsely full, sharp plastic pieces can cut through the stomach and cause infections and death. One tragic example is shown in Figure 12.5.7.

Human introduction of alien species

An **alien species** is one that is not native to the region in which it is found. There have been many occasions throughout history when an organism has been introduced from one ecosystem to another, whether it is:

- accidentally
- deliberately
- or for biological control of a pest organism.

Alien species can become invasive if they spread and modify their new environment and cause ecological damage. Invasive species can lead to a reduction in biodiversity in the areas they are introduced into, especially if they outcompete local species or have few natural predators.

Accidental introduction

The zebra mussel (*Dreissena polymorpha*) is a small freshwater species, originally native to lakes in southeast Russia. It has been accidentally released in many other areas, probably carried in ballast water of cargo ships. It has become an invasive species in many different countries. Zebra mussels are now found in the Great Lakes of the USA where they grow on docks and boats. They have spread into streams and rivers and block water pipes and interfere with water supplies (Figure 12.5.8). In some areas, they have outcompeted all other freshwater mussels because they grow in dense clumps. Zebra mussels are also believed to be the source of deadly avian botulism poisoning that has killed tens of thousands of birds in the Great Lakes since the start of the 21st century.

Figure 12.5.8: Masked workers use a water jet to clear zebra mussels clogging the pump room of Detroit Edison's power station in Michigan, USA. Zebra mussels also encrust water pipes and excrete a corrosive chemical.

Deliberate introduction

Many plants, collected in one part of the world, have been deliberately introduced to domestic gardens far away because of their attractive flowers or exotic foliage. Orchids, bamboos and rhododendrons are now seen all over the world but most were introduced following plant-collecting expeditions in the 19th and 20th centuries. In some cases, an introduced species finds the new conditions so advantageous that it becomes invasive. It grows rapidly and becomes a threat to endemic (native) species, which it outcompetes and eventually eliminates. One such example is Japanese knotweed (*Fallopia japonica*), which was deliberately introduced into European gardens in the 19th century for its attractive flowers. It reproduces vegetatively and even short sections of root can regrow to become whole new plants. This plant now covers huge areas of land in Europe. It can be controlled with herbicides, but there is a problem using these chemicals near rivers, as the herbicide gets into the waterway and upsets its ecological balance, harming plant and animal life.

No two species can occupy the same niche indefinitely because one will come to dominate and exclude the other. Both *Rhododendron* and Japanese knotweed have outcompeted and excluded native species and reduced biodiversity in the places where they grow.

12.5.3 Approaches to conservation of Biodiversity

People have come to realise that without concerted action we will lose the biodiversity of the Earth's habitats. There are many different approaches to conservation and many different organizations that are promoting conservation. No one approach will be suitable for every area and it is also difficult to quantify the value of a species or a habitat. Conservation arguments struggle to balance the ethical and aesthetic values with commercial considerations.

- economic arguments cite the valuation of ecotourism, genetic resources and natural capital
- ecological arguments centre on preservation of the ecosystem
- ethical arguments include the intrinsic value of a species.

Intergovernmental and non-governmental conservation organisations

The key objective of conservation organisations is to preserve species and their habitats throughout the world. Some organisations work at a local level while others are global. Different organisations are categorised according to the way they are set up and funded. Governmental organisations follow the policies of one or more governments and are funded by them. Non-governmental organisations (NGOs) are funded by individuals or independent groups. The effectiveness of the different organisations varies due to the different strategies they adopted in their work.

UNEP and WWF

United Nations Environment Programme (UNEP) is a governmental organisation which coordinates United Nations work on the environment and helps LEDCs to implement environmentally sound policies. UNEP was founded in 1972 and has its headquarters in Kenya. Its stated objectives are ‘to provide leadership and encourage partnership in caring for the environment by inspiring, informing and enabling nations and peoples to improve their quality of life without compromising that of future generations’.

UNEP gathers, collates and verifies data on biodiversity and ecosystems from many sources. This can be used as a reliable source of information. UNEP also promotes global and regional cooperation and develops environmental laws covering a range of issues from the atmosphere, marine and terrestrial ecosystems, to the green economy. Like many governmental organisations, it also works with NGOs to implement its policies.

The World Wide Fund for Nature (WWF) is an NGO and one of the best-known international conservation organisations. Since 1961 it has campaigned for the natural world and worked to ease pressure on the world’s natural resources. WWF is an independent organisation but around the world, it works with businesses, governments and local communities to create sustainable solutions that take account of the needs of both people and nature.

The organisation’s conservation work focuses on safeguarding wildlife and places it considers to be of global importance. It also lobbies governments and runs campaigns to change legislation and policy to protect the environment and biodiversity. Major campaigns have focused on climate change, energy, housing and the protection of the marine environment. It states that its ultimate goal has always been ‘people living in harmony with nature’ and finding ways to share the Earth’s resources fairly.

Some approaches to conservation include:

- conserving and protecting a natural habitat as a nature reserve
- *in situ* conservation
- *ex situ* conservation.

Conserving and protecting a natural habitat as a nature reserve should benefit all species. However, if population numbers are very low and a species are at risk, more active intervention may be required. Each nature reserve will have its own unique solutions to conservation problems. At Belsize Wood Nature Reserve, a small woodland reserve near the centre of London in the UK, nesting boxes for birds and bats have been put in place, because the number of mature trees providing suitable natural nesting sites is low. In a wetland nature reserve, nesting platforms that float on lakes can be beneficial and offer some protection against predators for nesting birds. At Sungei Buloh Wetland Reserve in Singapore, sluice management allows the control of water levels in the ponds. At any one time, the water level in at least one pond is kept low to expose the mudflats for shorebirds to feed and roost.

Figure 12.5.9: Walkways like this one enable people to observe wildlife without disturbing it.

Local people may not support the funding and existence of a nature reserve if they are not allowed into it. But, as the more people that visit a nature reserve, the more chance there is of habitats being damaged or destroyed. On the other hand, visitor access can have positive outcomes, if public awareness and knowledge of wildlife is improved. Usually, special trails or walkways are built at reserves to ensure that observers can visit safely without risk of damage to the surrounding habitats (Figure **12.5.9**). Legislation can also protect nature reserves from development and industrial activities.

In situ **conservation**

In situ **conservation** protects species within their normal habitat. This makes sense because each species has evolved to adapt to a particular environment. In situ conservation protects species in their own habitats by maintaining the environment, often within nature reserves or national parks. Protecting turtle nests using cages and fencing off an area of beach so that hatchlings can reach the sea is one example.

In situ conservation work may involve removal of invasive species: one example has taken place on Montague Island, one of the offshore islands in New South Wales, Australia. The island is home to several seabird species but because of the growth of large areas of non-native kikuyu grass (*Pennisetum clandestinum*) habitat that used to be used by nesting birds has been lost. The little penguin (*Eudyptula minor*), burrowing short tailed shearwaters (*Ardenna tenuirostris*), wedge-tailed shearwaters (*A. pacifica*) and sooty shearwaters (*A. grisea*) were suffering and their populations were declining. The Seabird Habitat Restoration Project aimed to remove the introduced grass which had smothered native vegetation, so that large expanses of seabird breeding habitat would be available and native birds could resume breeding there.

The project has proved highly successful in controlling and reducing the spread of kikuyu grass and restoring degraded seabird habitat so that the birds have been protected and their numbers can increase.

***Ex situ* conservation**

***Ex situ* conservation** involves preserving a species whose numbers are very low in a **captive-breeding programme** in a zoo or botanic garden to prevent it dying out.

In situations where *in situ* conservation is difficult or inadequate, *ex situ* conservation must be used. This is not ideal, because an organism behaves differently outside its natural habitat. However, it does give rise to the opportunity for captive breeding using scientific knowledge and modern technology. Techniques such as artificial insemination and embryo transfer may be used if animals fail to breed normally, and embryos can be preserved for later use. Difficult pregnancies can be monitored and the young cared for by staff.

An *ex situ* breeding programme has proved invaluable for the Arabian oryx (Fig 12.5.10). This animal, once almost extinct in the wild, has been successfully bred in a number of zoos in the USA and Europe.The DNA from the few remaining animals was compared and animals specially selected for breeding so that genetic diversity was maintained as far as possible.

Figure 12.5.10: Arabian oryx have been saved from extinction by ex situ breeding programmes

EXAM TIP

You do not have to remember all the Latin species names for organisms that you may write about in your exams.

Studying the behaviour of captive animals is key to breeding programmes. Some species with complex behaviours such as the giant panda from China are highly challenging to breed in captivity, but the centre at Chengdu in China has been very successful.

Plants are more straightforward to maintain in an *ex situ* situation. Botanic gardens can supply the correct environmental conditions for different plants and computer-controlled glasshouses can maintain the temperature and humidity that each requires. Many countries maintain 'national collections' of a variety of species including endemic plants, exotic genera and important food plants. There are also **seed banks** for many of the world's staple crops such as rice and maize. These preserve varieties of important crops, called **landraces**, which may be useful in the future to produce new varieties of food plants. At the Millennium Seed Bank at Wakehurst Place in England, seeds are kept in cool, dark conditions, which prevent germination, and can be stored for many decades. The Svalbard Global SeedVault, on the Norwegian island of Spitsbergen, holds duplicate samples of seeds held in gene banks worldwide, in an underground cavern.

Rewilding and reclamation

Rewilding is a means of conservation that aims to restore and protect natural systems and wilderness areas. Rewilding is a form of ecological restoration that tries to recreate an area's natural uncultivated state. We can help rewilding by creating the conditions an area needs to re-establish a stable, self-sustaining ecosystem with levels of diversity that existed before humans affected them. One way to summarise the important factors of rewilding is the three. Cs: Conservation of Cores, Corridors between areas and Carnivores. Carnivores are often keystone species (Section 12.3.8) and are essential in any balanced ecosystem.

Examples of rewilding include, protecting, enlarging and connecting ancient woodland to allow a range of wildlife to establish, breed and disperse. This may require a reduction in the number of grazing animals to help young trees and other vegetation grow. A larger area of woodland also increases the amount of carbon storage. Other ways of creating the right conditions for rewilding include removing dams or dykes to release the flow of water, reintroducing species that have disappeared and allowing natural forest to regenerate.

SCIENCE IN CONTEXT

A rewilding success story

Hinewai is an ecological restoration project occupying 1500 hectares on the South Island of New Zealand. Initially 109 hectares were privately purchased by the Maurice White Native Forest Trust in 1987 and botanist Dr Hugh Wilson began a project to allow introduced gorse to grow as a low canopy to restore farmland into native forest. The aim was to allow natural regeneration of native vegetation and wildlife with minimal interference and after 30 years of natural succession the vegetation and forest looks similar to the one that was present before clearance by humans; first Polynesian settlers from about 700 years ago and secondly by European settlers from about 1850. The native forest has regenerated, and birds and wildlife have returned. Dr Wilson has proved that nature can recover when given time and the opportunity.

Fools & Dreamers: Regenerating a Native Forest is a documentary film from ***HappenFilms*** about Hinewai Nature Reserve.

Figure 12.5.11: These biologists from the Rewilding Foundation evaluate a turtle inside the turtle reintroduction centre at El Impenetrable National Park, Chaco province, Argentina.

Reclamation is the practice of renewing land that has been damaged or degraded by agriculture or industries such as mining. Common disturbances include logging, damming rivers, intense grazing, hurricanes, floods, and fires. Reclamation activities try to replicate a pre-disturbance ecosystem or to create a new ecosystem through human intervention. They may include activities such as controlling soil erosion and waterways, reforestation by tree planting, removal of weeds and non-native species and replanting species that have been lost or replacing them with similar species that can survive in the reclaimed land.

The EDGE of Existence programm

KEY POINT

EDGE species are Evolutionarily Distinct and Globally Engandered

The **EDGE of Existence programme** is a research and conservation organisation developed by the Zoological Society of London. It aims to draw attention to the species that are thought to be the most Evolutionarily Distinct and Globally Endangered. Research and conservation plans of the programme are trying to halt the decline of species and take action to conserve them by training conservationists (called EDGE Fellows) to protect them.

The organisation has an interactive website which lists the top 100 EDGE mammals, reptiles, birds and amphibians and the top 25 corals that need urgent conservation. Each species is rated according to the rarity of the species and the current conservation efforts that are underway. Distinctive species do not have many closely related species and EDGE species are often the only surviving member of their genus. If species like these become extinct it would cause a significant loss of biodiversity and evolutionary history.

Examples of EDGE species include some well-known animals such as elephants and pandas but others such as the echidna, the bumblebee bat, the world's smallest mammal which weighs only 2 g, and the vaquita, the smallest of the porpoises that is found in the Gulf of California, are highly endangered, poorly understood and often ignored by other organisations.

NATURE OF SCIENCE

Cooperation and collaboration – conserving biodiversity requires international cooperation between scientists, organisations and politicians

In the last 50 years, the importance of biodiversity has come to the forefront of science. Species are not evenly distributed on Earth. Biodiversity is far richer around the tropics and areas containing rainforest are among the most diverse on the planet. People have come to realise that there are many compelling reasons for conserving the biodiversity of habitats such as the rainforests. Undiscovered species may provide valuable medicines and other resources for future generations. Conservation in one part of the world may depend on cooperation and collaboration in another and international organisations such as Worldwide Fund for Nature (WWF) and the United Nations Environment Programme (UNEP) coordinate such work in many countries. The key objective of all conservation organisations is to preserve species and their habitats. Some work at a local level while others are global. Some organisations, such as UNEP, are funded by governments while others, such as WWF, are non-governmental organisations (NGOs), which are funded by individuals or groups. Organisations such as WWF work with businesses, governments and local communities to create solutions that take account of the needs of both people and nature.

Conservation programmes must select which species are to be protected, but it is often difficult to decide which species most merit conservation efforts. On what basis should one species be chosen over another? For example, is a large mammal such as a tiger or panda more important than a small, seemingly insignificant mollusc? A striking or endearing mammal may encourage people to support a conservation programme but smaller, less appealing species may, in fact, be more important and play a pivotal role in an ecosystem. Should endangered animals be given priority over other species whose numbers are not yet so low?

The choice of species for ex situ conservation can also be difficult, and many factors must be considered. For example, when zoos select animals for captive breeding programmes, certain animals with aesthetic appeal are likely to increase visitor numbers and therefore raise public awareness and attract greater financial support for conservation. If these animals are returned to the wild, they may engage local people who could benefit from ecotourism. On the other hand, choosing a species for ecological reasons is more likely to benefit a whole ecosystem – assuming the programme does not fail through lack of funding and support.

Science can support conservation efforts by providing the expertise needed to ensure breeding programmes are successful. Different zoos have different areas of expertise and are likely to be more successful at ex situ conservation with some species than with others, so this factor too will influence the organisms whose preservation is prioritised.

Linking questions

How does variation contribute to maintaining stability in an ecosystem?

INTERNATIONAL MINDEDNESS

The IUCN Red List

The International Union for Conservation of Nature and Natural Resources (IUCN) is an organisation dedicated to nature conservation in all countries of the world. It has assessed which species are most at risk, based on data about critically endangered, endangered and vulnerable species. The IUCN Red List of Threatened Species is the world's most comprehensive information source on the global conservation status of animal, fungi and plant species. The Red List is an indicator of the health of the world's biodiversity. The IUCN estimates that 40% of amphibians and 26% of mammals are under serious threat and that many smaller, invertebrate organisms may become extinct before they have even been discovered and given names.

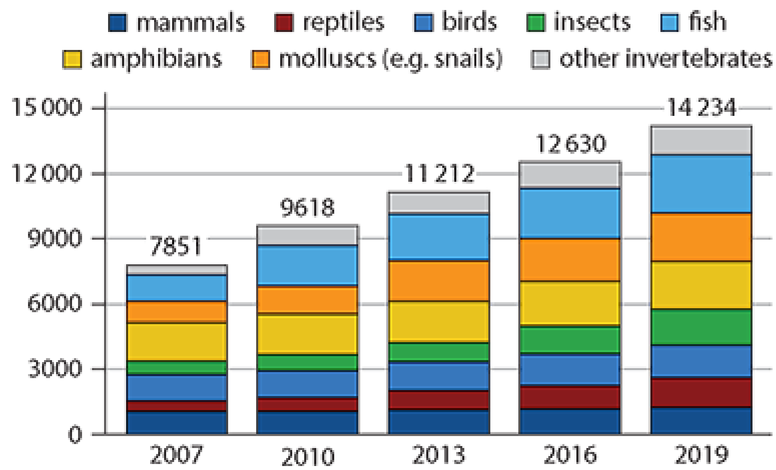

Figure 12.5.12: The number of endangered animal species, from the IUCN Red List.

12.5.4 Eutrophication - human activities and the nitrogen cycle

The nitrogen cycle

Nitrogen is a vital element for the formation of proteins and nucleic acids in the bodies of plants and animals. However, although almost 80% of the Earth's atmosphere is nitrogen gas, it is so stable that it cannot be used directly by living organisms, and nitrogen is often in short supply as a nutrient. It is recycled in ecosystems through the actions of many organisms including nitrogen fixing bacteria, nitrifying bacteria and denitifrying bacteria.

Plants obtain the nitrogen they need to grow in the form of nitrates, which they absorb from fertile soil through their roots. All nitrates are soluble and can be absorbed by plants.

The following are good for plant growth:

- nitrogen fixation, which converts nitrogen gas to useful nitrates
- nitrification, which converts ammonia to useful nitrates.

But the following is bad for plant growth:

- denitrification, which converts useful nitrates into nitrogen gas that plants cannot use. This takes place in anaerobic conditions in compacted or waterlogged soil.

Eutrophication

Human activities such as agriculture have interfered with the natural cycling of nitrogen. Nitrates and phosphates are added to the soil in the form of fertilisers, animal manure and sewage, which all contribute to eutrophication. Eutrophication is defined as the natural or artificial addition of nutrients (especially nitrates and phosphates) to water, which leads to a reduction or depletion of the oxygen content of the water.

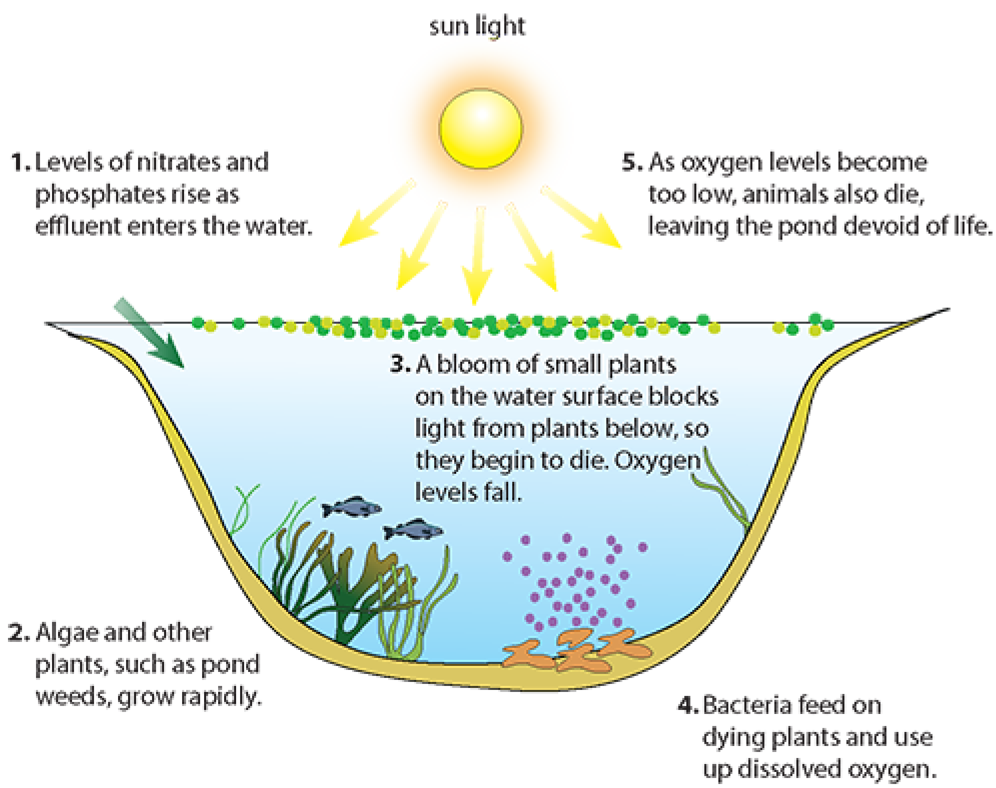

Figure 12.5.13: Eutrophication in a pond ecosystem.

KEY POINT

biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic organisms to break down organic material in water, at a certain temperature, over a certain period of time.

Excess fertiliser can run off the land, particularly in areas where large numbers of livestock are kept or where slurry (produced from animal waste and other organic matter) is used as a fertiliser. Soil erosion also deposits both manure and artificial fertilisers in waterways, and the problem is worse where forests have been cut down and leaching (washing out) of soluble minerals from the soil by rainwater is increased. Excess nitrate and phosphate flowing into waterways and ponds can cause ecological problems and eventually lead to eutrophication. The process is summarised in Figure 12.5.13. In many countries, fertiliser use is controlled, and in modern farming the requirements of crop plants are closely monitored because of the high cost of fertiliser.

Aquatic systems produce and consume oxygen (Figure 12.5.13). The number of aerobic microorganisms and their rate of respiration at any particular location in a river or stream determine the **biochemical oxygen demand (BOD)**. The greater the BOD the more rapidly oxygen is depleted, resulting in less oxygen being available to other forms of aquatic life. When this happens aquatic organisms can become stressed, suffocate and die. BOD is used as an indirect measure of the amount of organic matter in a water sample. Oxygen demand can be increased by excess growth of algae and by other oxygen-demanding factors such as decaying plants and animals, animal waste and effluent from wastewater treatment plants.

12.5.5 Biomagnification

Some chemicals used in the environment as pesticides are taken into the bodies of non-pest species where they remain and accumulate because the organism cannot break them down and excrete. Insecticides such as DDT and dieldrin are well studied examples of the way toxic chemicals can accumulate in the environment by **biomagnification**.

KEY POINT

biomagnification is the process by which chemical substances accumulate to progressively more concentrated levels at each trophic level in a food chain.

Small quantities of these insecticides, used to control pests, are sprayed into the environment where they may be absorbed by plants, or fall on the surface of their leaves. The plants may be unaffected, but when primary consumers feed on the sprayed plants they take in a far greater quantity of the toxin. The chemical remains in the bodies of the primary consumers and if a secondary consumer feeds on a number of these animals, it accumulates an even greater amount of the chemical.

DDT is an organochlorine insecticide that was widely used to kill mosquitoes that carry the malarial parasite. It is stored in the fatty tissues of animals that have ingested it. We now know that it is not readily biodegradable and can remain in the environment for up to 15 years. The first signs of the damage it can do were noticed in a survey of peregrine falcons in Europe in the 1960s, which showed that the peregrine population was declining in number. Their bodies contained high levels of DDT, which caused the shells of the birds' eggs to be thinner than normal. As females tried to sit on their eggs to incubate them, the eggs broke.

The effects of DDT were reported in many other parts of the world in a variety of wild bird populations. Even penguins in Antarctic regions were found to have the chemical in their bodies.

Although the original concentration of DDT used in insecticide sprays was low, at about 3 parts per million, the chemical ran into waterways and was taken up by microscopic plants in rivers and lakes. When microscopic animals ate these plants, the DDT became more concentrated in their bodies. Small fish feeding on the microscopic animals accumulated about 0.5 ppm in their body fat and fish-eating water birds, such as the osprey, had about 25 ppm of DDT in their bodies (Figure 12.5.14).

DDT was a successful insecticide because it remained effective for a long time without breaking down, but its damage to the environment was considerable. Since the 1970s, it has been banned in most countries, although it is still legal to use it in some parts of South America, Africa and Asia. Slowly, wild bird populations have recovered from its effects.

SCIENCE IN CONTEXT

Minamata Bay and mercury poisoning

Minamata is located on the coast of Japan’s westernmost island. The city and the adjacent Minamata Bay form a relatively closed ecosystem. The bay used to be a source of fish for the residents of the city, until the mid-1950s when people started to fall ill with an unknown neurological condition. They suffered increasing loss of motor control when walking or carrying out simple everyday tasks.

Sometimes they became partly paralysed and were unable to see or speak properly. It took more than 5 years for medical researchers to identify the cause as mercury poisoning from eating the fish and shellfish from Minamata Bay. The source of the problem was the town's Chisso Corporation factory which had been manufacturing acetaldehyde to produce plastics since the 1930s. Mercury from the production process spilled into the bay and entered the food chain. At that time, Minamata residents relied almost exclusively on fish and shellfish from the bay as their source of protein.

Direct evidence that mercury was responsible was not confirmed until nearly 100 people had been identified as suffering from poisoning and more than 20 had died. Mercury is still present in the sediment of the bay, where fishing remains prohibited. Mercury accumulated in the food chain because animals that lived in the bay and fed on contaminated food were unable to break it down. When people in the area ate fish from the bay, they ingested mercury with each meal until the amount in their bodies reached dangerous levels.

To consider:

1 How do you think incidents such as Minamata Bay have influenced present-day thinking about environmental issues?

2 Suggest two reasons why the problem of mercury poisoning was not identified and dealt with until 1956, even though the factory had been operating since the 1930s.

3 Research methods of removing mercury and other poisonous metals from ecosystems that are polluted with them.

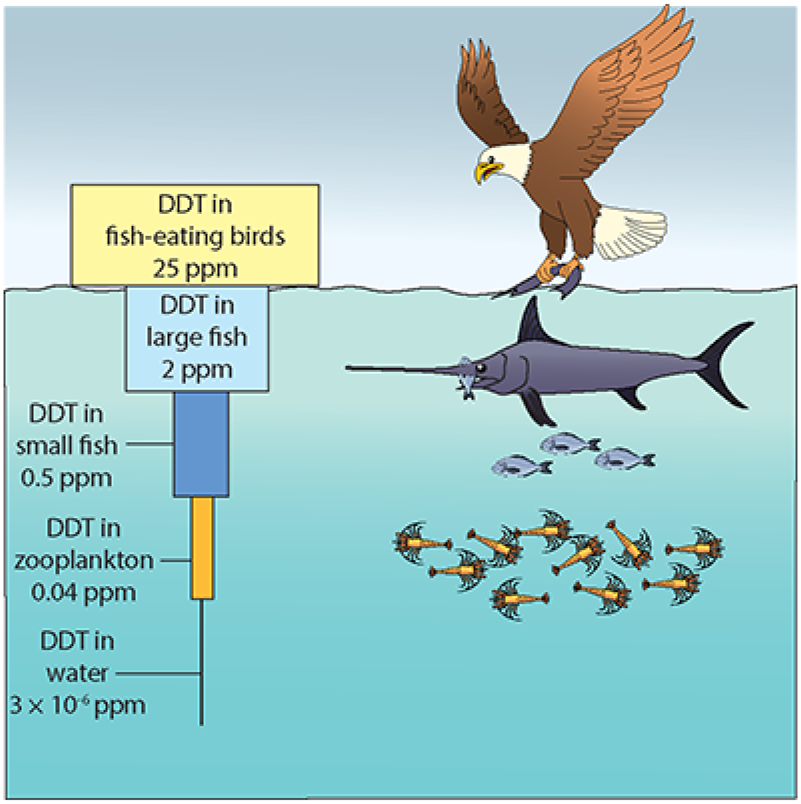

Figure 12.5.14: An example of how DDT concentrations increase up the trophic levels of an estuarine food chain.

Heavy metals and industrial chemicals such as polychlorinated biphenyls (PCBs) that are also released into the environment remain a problem for living organisms. This is because these chemicals accumulate in a similar way.

TEST YOUR UNDERSTANDING

34 Define a keystone species.

35 Summarise how nitrate fertilisers disrupt the nitrogen cycle.

REFLECTION

Could I summarise the effect that humans have had on ecological relationships and the survival of organisms? Which factors would I describe first to a classmate?

Links

- How do food chains and webs transfer matter and energy in ecosystems? (Chapter 12.2)
- How do human activities affect the evolution of species? (Chapter 11.3)

12.6 Climate change

LEARNING OBJECTIVES

In this section you will:

- recall the ways in which humans have caused climate change
- understand that there is positive feedback in global warming
- recall that forest ecosystems may reach a tipping point if changes continue
- learn that habitats will change as sea ice melts
- learn that changes in ocean currents will change nutrient upwelling
- recall the threat to coral reefs of climate change
- understand some measures that are being taken to restore ecosystems

> recognise some factors that influence the timing of events such as flowering and migration

> understand that changes to these factors may disrupt the growth reproduction and development of some species

> recognise that evolution is one consequence of climate change

GUIDING QUESTIONS

- What are the main factors causing climate change?
- How does climate change affect ecosystems?

12.6.1 Human causes of climate change

The greenhouse effect

Certain gases, the most important of which are carbon dioxide and water vapour, enable the atmosphere to retain heat. Without these gases in the atmosphere, the Earth's temperature would be too low to support life. The warming effect of these gases is known as the **greenhouse effect** because it is caused in a similar way to the warming of a greenhouse.

A greenhouse is made of glass, which allows shortwave radiation from the Sun to pass through it. As the sunlight passes through the glass, the radiation is absorbed, changed into heat – which has a longer wavelength – and re-radiated. Glass is less transparent to these long wavelengths and heat is trapped in the greenhouse, making it warmer inside. So-called 'greenhouse gases' in the Earth's atmosphere (such as carbon dioxide, methane and water vapour) act in a similar way to the greenhouse glass. They trap heat that is radiated from the Earth's surface and keep the Earth at a comfortable temperature for life to exist (Figure 12.6.1).

Carbon dioxide currently forms only 0.04% of the atmospheric gases but it plays a significant part in the greenhouse effect. Other greenhouse gases include water vapour, methane, oxides of nitrogen and fluorocarbons (FCs). Methane is estimated to have more than 80 times more warming power than carbon dioxide, even though the effect of carbon dioxide in the atmosphere lasts longer. Estimates suggest that about 25% of global warming is currently due to methane from human activities

The human population has increased dramatically in recent history and the demand for energy in industry, transport and homes has also increased. Most of this energy demand has been met by burning fossil fuels, mainly oil, coal and gas. Burning fossil fuels releases both carbon dioxide and oxides of nitrogen.This activity has raised the concentration of carbon dioxide in the Earth's atmosphere significantly since the mid-1800s, a period which has coincided with increasing industrialisation (Figure 12.6.2).

The influence of increased concentrations of greenhouse gases has produced changes in global temperatures and climate patterns. Rising levels of greenhouse gases are believed to be causing an enhancement of the natural greenhouse effect. Scientists have shown that the Earthis experiencing a rise in average global temperature, known as **global warming** (Figure 12.4.6) which is thought to be happening because of this enhanced greenhouse effect. Climatologists are concerned that, as a result of all this activity, humans are upsetting the balance of the carbon cycle and adversely affecting our atmosphere. (You can review the stages of the carbon cycle in Section 12.2).

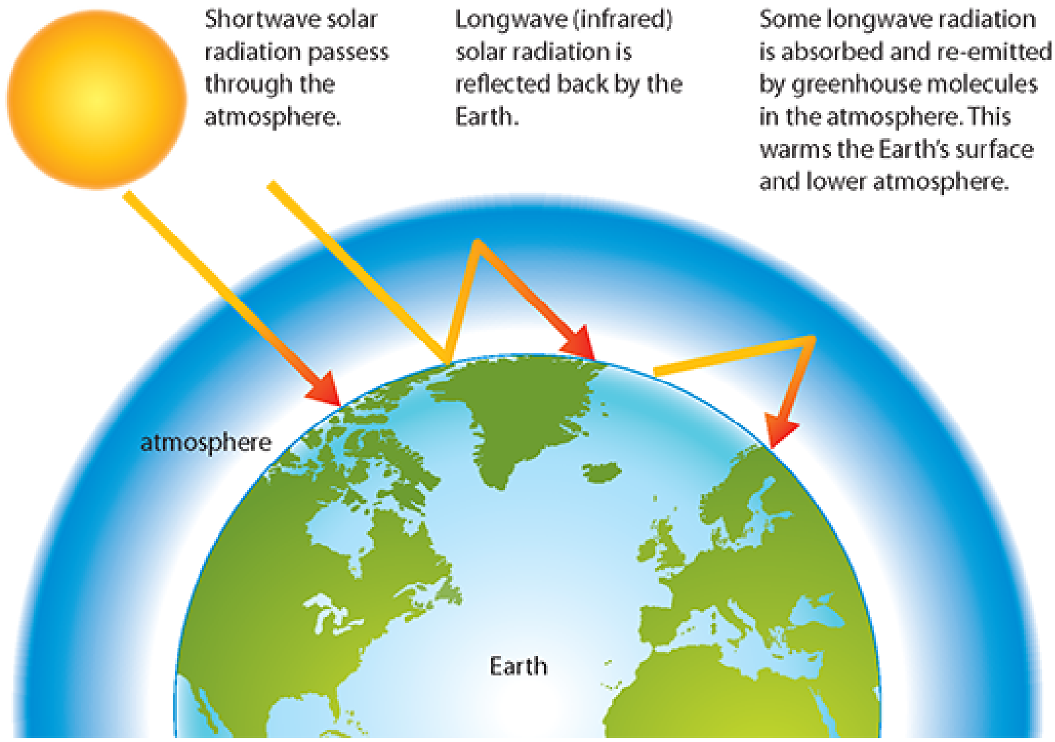

Figure 12.6.1: Greenhouse gases trap heat, warming the atmosphere.

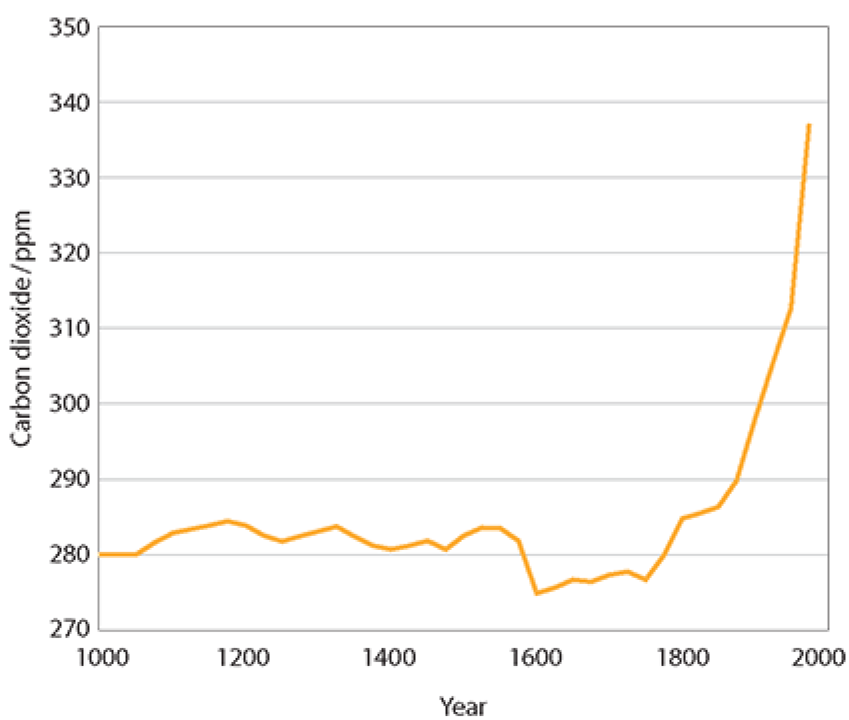

Figure 12.6.2: Graph to show increase in carbon dioxide concentration in the atmosphere since the start of industrialisation

The consequences of climate change are wide ranging and varied. Some results of global warming are likely to be:

- melting of ice caps and glaciers
- a rise in sea levels, causing flooding to low-lying areas
- changes in the pattern of the climate, winds and ocean currents
- changes in ecosystems and the distributions of plants and animals
- increases in photosynthesis as plants receive more carbon dioxide.

As the atmosphere warms, it causes sea ice to melt. Ice is white and reflects solar radiation, while the darker ocean surface absorbs more solar radiation. As the oceans absorb more heat, this causes more ice to melt and warms the Earth further. This effect is known as the ice-albedo feedback and it is a **positive feedback** system. More warming leads to more melting which leads to more warming. Deposits of frozen methane and carbon dioxide are also locked up in the biomass and decomposed biomass that is contained in the permafrost in polar regions. Permafrost is ground that remains below 0°C for more than two years and it covers about a quarter of the Northern Hemisphere. As the environment warms and the permafrost thaws, methane and carbon dioxide can be released into the atmosphere and contribute to the positive feedback effect of global warming. Carbon dioxide is naturally stored in the ocean either as a dissolved gas or in the form of carbonates. Global warming also causes more of this carbon dioxide to be released.

- As land and sea ice melt habitats for animals which live on the ice are lost. In the Antarctic the breeding grounds of the emperor penguin may be lost while in the northern hemisphere, the sea ice habitat of walruses and polar bears could be lost.

- Warmer temperatures and less snowfall in the cold boreal forests which extend across the northern USA, Canada, Scandinavia and Russia may lead to drought in these areas of taiga biome. Without water the trees turn brown and primary production falls. Warmer temperatures cause the peatland to dry out and hotter drier conditions are leading to more wildfires which in turn speed up the melt of permafrost. Peatlands store twice as much carbon as all the world's forests so a change from net carbon accumulation to net carbon loss could prove to be a tipping point in ecosystem stability, like that seen in boreal forest and rainforest.

- Ocean currents transport warm water and rain from the equator toward the poles and cold water from the poles to the tropics, rather like a global conveyor belt. Ocean currents regulate the global climate and distribute solar radiation. Ocean currents are found both at the ocean surface and in deep water. Water moves not only horizontally but vertically. In upwelling currents vertical movements bring cold nutrient rich water to the surface and send denser cold water downward. If global warming heats the surface waters, nutrient upwelling may be prevented so that primary production in the oceans and energy flow in marine food chains is reduced.

- Effect on coral reefs – Coral reefs are fragile ecosystems, which are very sensitive to rising carbon dioxide levels. They are sometimes known as the ‘rainforests of the sea’ because of their extensive biodiversity which includes large numbers of fish and other species. Coral polyps extract calcium from seawater and use it to build the elaborate limestone skeletons that make up a coral reef. Most reef-building corals contain photosynthetic algae, called zooxanthellae, which live within their tissues. The corals and algae have a symbiotic, mutualistic relationship: the coral provides the algae with a protected environment and inorganic nutrients, while the algae produce oxygen and help the coral to remove waste products. Zooxanthellae also supply the coral with essential compounds from photosynthesis and produce the wide range of colours that are seen in corals. Corals respond to the stress of higher sea temperatures which result from global warming by expelling these algae – an event known as coral bleaching (Figure 12.6.3). Some coral can recover from bleaching but often the coral dies, and the entire reef ecosystem disappears. Coral reefs also suffer as a result of ocean acidification which occurs when higher CO_2 levels in the atmosphere cause the oceans to absorb more carbon dioxide. Acidic oceans may inhibit the growth of producers and affect food chains generally, but in a more acidic ocean, calcium dissolves more easily and corals cannot form their skeletons properly so their growth slows down. It has been estimated that a doubling of atmospheric carbon dioxide will reduce calcification in some corals by as much as 50%. Predicted rises in sea level caused by melting sea ice could also affect some reefs by making the water too deep to allow adequate sunlight to reach them.

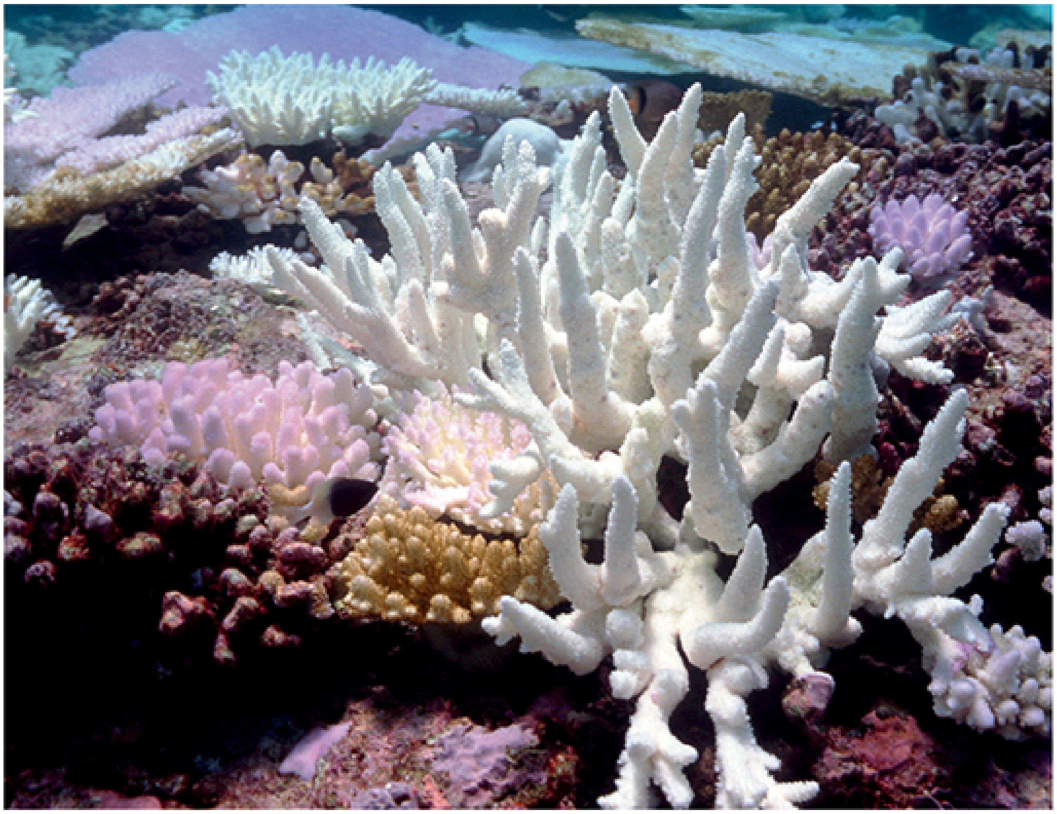

Figure 12.6.3: Coral bleaching.

- Range shift in temperate species – As the climate change alters the conditions in environmental niches, species are shifting their habitat ranges towards areas and conditions to which they are adapted and can survive. Individual species' ability to tolerate change decides which ones need to move and how far. In Europe a study of birds and butterflies showed that butterflies had moved further north to reach cooler conditions by 114 km while birds moved an average of 37 km north. Movements like these enable a species to survive but, as they arrive, incoming species can disrupt the structure of the community that lived there. For example, as the tundra warms and is being taken over by boreal forest, many species such as the arctic fox and snowy owl are losing their habitats. And as rivers and streams warm up, fish that survive in warmer waters are expanding their ranges into areas that were occupied by cold water species and cold water fish such as trout are losing their habitats.

NATURE OF SCIENCE

Forest regeneration and restoration of peatlands

In Section 12.5 the possibilities of restoration and regeneration of ecosystems were discussed. Tree planting and the establishment of new forests is taking place all over the world.

Native woodlands and peatlands are two of our largest natural climate regulating ecosystems. They both have high biodiversity and are a priority for conservation and restoration. It is generally agreed that sustainable management and enhancement of both peatlands and woodlands are necessary to support biodiversity and reduce climate change. Many trees have been planted on peatlands to provide timber and to absorb carbon, but is new forest planting on peatland the best thing to do? Some of the plantations that have been established on peatlands are now being removed so that peatland can be restored.

Growing trees on peatland is not the most sustainable or cost-effective option for tackling climate change. The amount of carbon absorbed by trees on peatlands is not as high as that of trees grown on non-peat soils and planting trees on peat costs more to manage than planting in a forest.

The environmental importance of lower carbon absorption from trees on peatland must be considered and compared with the alternative of simply restoring the peatland. The optimum solution for both carbon absorption and biodiversity seem to be to maintain peatlands which have not been planted with trees, restore forested peatland to open habitat and plant new trees on non-peat soils or other areas that can benefit the peatlands.

To consider:

1 Why is tree planting such an important aspect of restoration projects?

2 What other methods might be successful in restoration of a habitat?

12.6.2 Timing of biological events and global warming

KEY POINTS

phenology is the study of cyclic and seasonal events of plants and animals in relation to climate

photoperiod is the length of the day – how much light species receive over 24 hours

Phenology, the timing of annual cycles of plants and animals, is very sensitive to changes in climate. Organisms adjust the timing of certain events such as flowering or migration depending on changes in weather. The timing of these events provides information about climate change to investigators and others who monitor the growth of crops and forests. Changes in the phenology of species are one of the most obvious consequences of climate change as temperature increases and is the major abiotic factor that affects the seasonal timing of life histories and synchrony between different species.

The Arctic mouse ear chickweed (*Cerastium arcticum*) is a small plant that grows in southern Greenland, Iceland, Scotland and Norway. It has white flowers and grows in tufts in loose gravel, it forms part of the vegetation of the ecosystem and provides food for reindeer in summer. The chickweed has been affected by warming of the soil in winter. Climate change affects all seasons, but warming is more pronounced in winter than summer at high latitudes. Snow cover is important in ecosystem processes, but winter warming is decreasing the amount of cover and snow depth. Taller more productive species benefit from a longer growing season without snow and become dominant, out-competing smaller, species such as mouse ear chickweed by shading them out. Changes like this cause changes in community composition which lead to changes not only in the above ground species but also to nutrient cycles and decomposition in the soil.

Figure 12.6.4: Alpine mouse-ear or alpine chickweed (Cerastium alpinum) growing on a hillside at the Ilulissat Icefjord in Greenland during unseasonably warm weather.

Migrating reindeer (*Rangifer tarandus*) live in boreal and montane ecosystems in the Arctic, but many populations are declining due to changes in their habitat. In the summer months reindeer eat mosses, herbs, such as mouse ear chickweed, ferns, grasses, and the shoots and leaves of shrubs. This diet is important for growth of their young, pregnancy and lactation in females. In winter, they scrape away snow with their hooves to feed on lichen (also called reindeer moss) and fungi. As the Arctic warms, vegetation patterns are changing. Climate change has changed the plants that grow in the Arctic and more rain and warmer winters mean that plants are covered with ice instead of snow. Ice prevents reindeer reaching the lichen beneath it.

Reindeer will need to adapt their range to the changed availability of food if they are to survive.

Another example of the effect of changing temperature on animal behaviour and feeding has been studied in an English oak woodland which is home to the bird, the great tit (*Parus major*). Over the last 60 years records show that temperatures have increase by 2.6°C. In response to this warming the birds have changed the timing of their mating and egg laying so it is now 16 days earlier in the spring than 60 years ago. Great tits feed their young on caterpillars, which they find living on oak tree leaves. But as spring has come earlier in the year oak leaves and caterpillars have been appearing earlier too. But the leaves and caterpillars are appearing even earlier than the young in the nests of the Great tits and this could mean that they could soon be out of synchrony with them.

Figure 12.6.5: Bark beetle on a dead spruce in the Harz mountain region in Germany. In April and for the previous two summers, there was very low rainfall so forests were stressed and more susceptible to pests.

Increases in number of insect life cycles

The spruce bark beetle (*Ips typographus*) is the most important bark beetle pest species in conifer forests of Europe, primarily attacking Norway spruce (*Picea abies).* Bark beetles infest and reproduce in the trees and can cause trees to die over a large area. In the United States species in the genera *Dendroctonus* and *Ips* are the primary pest species and in the years between 1997 and 2010 more than 5 million hectares of trees were affected by bark beetles. Bark beetle outbreaks have intensified in forests all over the world recently and are expected to increase further because of climate change.

Bark beetles have adapted to changing local conditions. Species that infest and reproduce in trees in warmer habitats have evolved mechanisms that allow them to produce several generations in a single year. Species with host trees in colder climates such as the spruce beetle have evolved to survive during cold winters and emerge as adults to attack trees during warm summer months. The effect of warming temperatures differs depending on the species and the season of warming but as changes in climate continue, many trees will be exposed to less suitable growing conditions and may become more susceptible to bark beetle attacks.

Evolution as a consequence of climate change

As climate change and warming temperatures have caused a reduction in snow cover there is one clear example of a species evolving to adapt to the changes.

Tawny Owls in southern Finland are evolving by changing the colour of their feathers. A study over about 30 years has recorded an increase in dark brown owls in the population that until recently has been dominated by light grey birds (Figure 12.6.6) which blend in with the pale snow coloured land. It may be that selection pressure is no longer favouring the pale owls but the advantages that the dark owls have is still not clear as both colour birds seem to survive equally well. Natural selection acted in a similar way on the Peppered moth in the1800s in the UK when darker coloured individuals had an advantage in soot-covered trees (Section 11.2.2). We may well see natural selection acting on more species as climate change alters the conditions in the environment.

Figure 12.6.6: A grey tawny owl is camouflaged in a snow-covered terrain.

TEST YOUR UNDERSTANDING

36 Outline the effect of climate change on ocean currents

37 How are coral reefs affected by climate change?

38 Define phenology

REFLECTION

Could I summarise the effect that humans have had on ecological relationships and the survival of organisms? Which factors would I describe first to a classmate?

Links

- How do food chains and webs transfer matter and energy in ecosystems? (Chapter 12.2)
- How do human activities affect the evolution of species? (Chapter 11.3)

SELF-ASSESSMENT CHECKLIST

Think about the topics covered in this chapter. Which parts are you most confident with? Which topics require some extra practice?

I can...	Subsection	Needs more work	Nearly there	Confident to move on
distinguish between autotrophs and heterotrophs and chemosynthetic autotrophs	12.1.1			
identify *Euglena* as an autotroph and a heterotroph	12.1.1			
define consumers and saprotrophs by their methods of feeding	12.1.1			
outline the concept of trophic levels	12.1.1			
classify consumers as primary,	12.1.1			

secondary or tertiary consumers based on their diets				
describe the complexity of some trophic feeding relationships	12.1.2			
explain the adaptaions of carnivores, herbivores and humans to their method of feeding	12.1.2			
identify categories of heterotrophs that do not fit easily into food webs	12.1.2			
recognise other feeding relationships including mutualism, parasitism and commensalism	12.1.2			
state that most ecosystems rely on light energy from the Sun and	12.2.1			

that this is converted to chemical energy by photosynthesis				
autotrophs use carbon compounds for their energy needs	12.2.1			
describe how chemical energy in carbon compounds flows through food chains	12.2.1			
summarise how energy is lost as heat from ecosystems and from trophic levels as dead organic material	12.2.1			
state that energy losses limit the length of food chains and biomass accumulation	12.2.1			
describe how food chains and webs are represented in	12.2.1			

pyramids of energy				
distinguish between energy flow and nutrient cycling in an ecosystem	12.2.2			
summarise the events of the carbon cycle				
explain the terms population and community	12.3.1			
describe how to estimate populations using random sampling and the Lincoln index	12.3.2			
use the chi-squared test to assess whether there is association between two species	12.3.2			
outline the effects of intraspecific and interspecific competition	12.3.4			

draw and interpret population growth curves	12.3.3			
define the terms carrying capacity, density-dependent factors and density-independent factors, and explain their effects on population growth	12.3.3			
explain the difference between intra- and interspecific relationships	12.3.4			
summarise the effect of cooperative interspecific interactions (mutualistic) on plants and fungi	12.3.4			
describe the advantages and disadvantages of cooperative intraspecific relationships	12.3.4			

define and give examples of allelopathic relationships in plants, fungi and bacteria	12.3.5			
describe the effects of predator–prey interactions and how these can be modelled	12.3.6			
outline defence mechanisms used by prey animals and plants to avoid being eaten	12.3.6			
recognise that ecosystems may remain stable for long periods of time	12.4.1			
describe why some ecosystems may be reaching a tipping point	12.4.1			
describe the features of a mesocosm and define a	12.4.1			

sustainable ecosystem				
describe conditions that are required for sustainable harvesting from natural ecosystems	12.4.2			
describe factors affecting sustainability of agriculture	12.4.2			
outline human impacts on biogeochemical cycles	12.4.3			
define the terms ecological succession and climax community	12.4.4			
distinguish between primary, secondary and cyclical succession	12.4.4			
describe how human activities can prevent a	12.4.4			

climax community developing				
outline the factors needed for a stable ecosystem	12.5.1			
distinguish between non-renewable and renewable resources	12.5.1			
recall how tipping points can lead to irreversibe change	12.5.1			
outline how mesocosms can be used as models to investigate ecosystem stability	12.5.1			
recall the reasons for ecosystem loss	12.5.1			
summarise the causes and consequences of the 6th mass extinction	12.5.1			
list some of the ways humans	12.5.1			

interfere with stable ecosystems				
summarise the dangers of microplastics in the environment	12.5.2			
define an alien species and outline the problems they cause	12.5.2			
explain the difference between in situ and ex situ conservation, rewilding and regeneration	12.5.3			
explain how human activities disrupt the nitrogen cycle and cause eutrophication	12.5.4			
explain the importance of a keystone species	12.5.5			
define biomagnification and its effect on	12.5.5			

higher level consumers				
recall the reasons that are leading to climate change	12.6.1			
list the effects of climate change on ice melts, ocean currents, species ranges and coral reefs	12.6.1			
explain what is meant by a phenology and give examples of phenological events	12.6.2			
explain how climate change can lead to evolution.	12.6.2			

EXAM-STYLE QUESTIONS

You can find questions in the style of IB exams in the digital coursebook.

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