CHAPTER

4 Land cover change

Land cover change describes human modifications made to the Earth's surface. For thousands of years, this was done to obtain food and other resources. However, the current rate and intensity are unprecedented, leading to large-scale changes in ecosystems and environmental processes on local, regional and global scales. These changes include the warming of the planet, biodiversity loss and the pollution of water, soils and air.

Mitigating the negative consequences of land cover change, while sustaining the production of the resources needed to sustain our way of life, are among the greatest challenges facing humanity.

This chapter covers the nature, extent and outcomes of land cover change. It explores the natural cycles and processes in tandem with the role humans play in modifying global systems and how this contributes to land cover change. Deforestation, desertification and melting glaciers and ice sheets are investigated. Climatic and glacial cycles, geomorphic processes, and invasion and ecological succession of vegetation communities are also further explored.

> **We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.**
>
> **Aldo Leopold, American author, philosopher, scientist, ecologist, conservationist and environmentalist.**

4.0.1 Clearing rainforest for plantations

Chapter glossary

afforestation the planting trees, or sowing seeds, to create a forest in a barren land devoid of any trees

algal bloom a rapid increase or accumulation of algae in a waterway

anthropogenic caused by humans

bioaccumulation when substances, especially toxins, remain within an organism and increase with repeated exposure or ingestion

climax community the final stage of succession, in which the mix of species remains relatively stable until a disturbance such as fire occurs.

eutrophication water pollution involving excess nutrients, often from fertilisers or sewage

evapotranspiration physical, chemical and biological changes that take place after a lake, estuary or slow-flowing stream receives inputs of nutrients and phosphates from natural erosion and run-off from the surrounding drainage basin

feedback loop occurs when an output of matter or energy is fed back into the system as an input and leads to changes in that system

geomorphology the study of landforms, including their origin, evolution, form and distribution.

glaciation the process or state of being covered by glaciers or ice sheets

habitat fragmentation the breakup of a habitat into smaller pieces, usually because of human activities

heat island an urban area that is significantly warmer than its surrounding rural areas due to human activities and the nature of the constructed environment

herbaceous plants plants without woody stems

hydrological drought drought that occurs when the surface flow (river flow) and lakes or reservoir levels decline below the long-term mean

land cover the physical and biological features of Earth's surface

periglacial the area marginal to a frozen or ice-covered region and which is subject to the seasonal effects of freezing and thawing

permafrost a subsurface layer of soil that remains frozen throughout the year, mostly found in polar regions

plant succession the change in the types of plant species occupying a given area over time

Pleistocene the geological epoch that lasted from about 2 580 000 to 11 700 years ago

primary succession ecological succession in an area without soil or where the soil is incapable of sustaining life (because of recent lava flows, newly formed sand dunes, or rocks left from a retreating glacier)

secondary succession ecological succession in an area in which natural vegetation has been removed or destroyed (for example by fire) but the soil has not been destroyed

shrub a woody plant, under 5 metres tall if it has a single main stem or 8 metres if it has multiple stems

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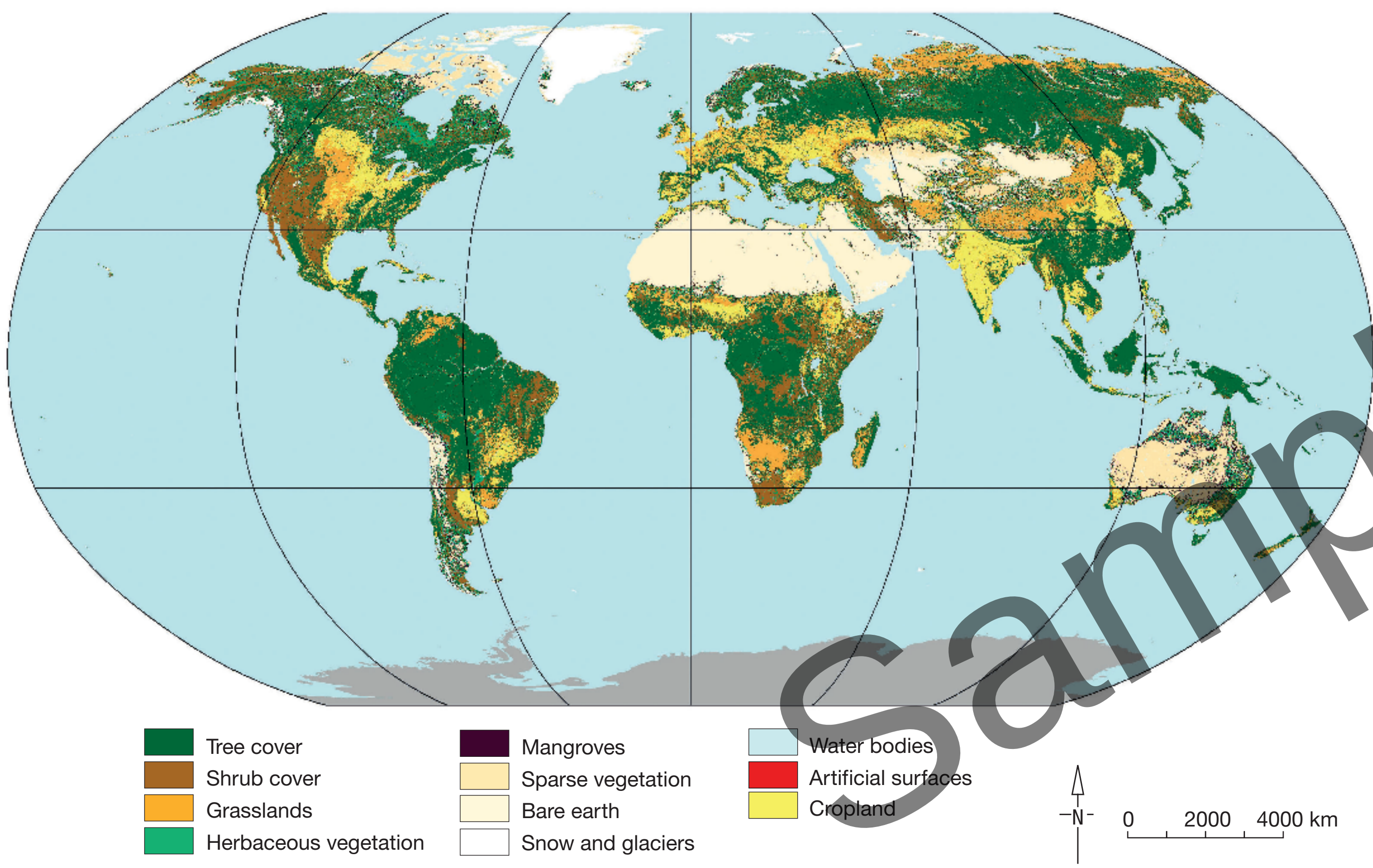
UNIT 4.1

Nature and extent of land cover

Land cover refers to the physical and biological cover of Earth's surface. It includes natural features like water bodies (oceans, seas, lakes and rivers), areas of ice and snow, vegetation, and exposed rock and soil. It also covers constructed and managed environments (e.g. buildings, roadways, agricultural land).

Land cover types

Many land cover classification systems exist with the most recent and widely used being The Global Land Cover-SHARE, developed by the UN's Food and Agriculture Organization's (FAO) Land and Water Division. It identifies 11 thematic land cover layers (see Figure 4.1.1).

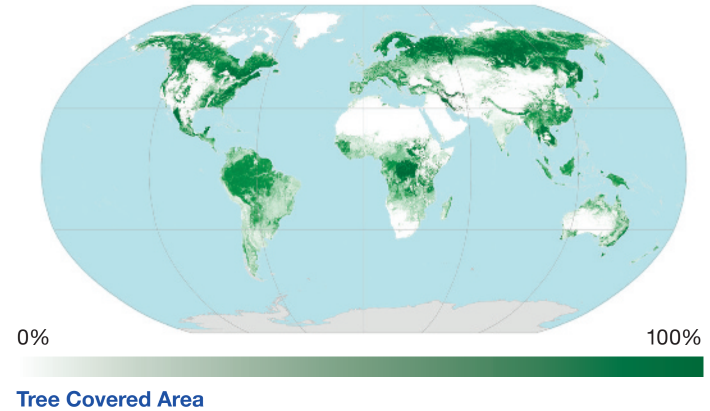


4.1.1 Global distribution of land cover types as defined by the UN's FAO

Tree cover

Any land with a natural tree cover of 10 per cent or more is considered a tree-covered area. This category included areas planted as an **afforestation** project, areas seasonally or permanently flooded with fresh water, and coastal mangroves (see Figures 4.1.2 and 4.1.3).

4.1.2 Tree cover in a tropical rainforest



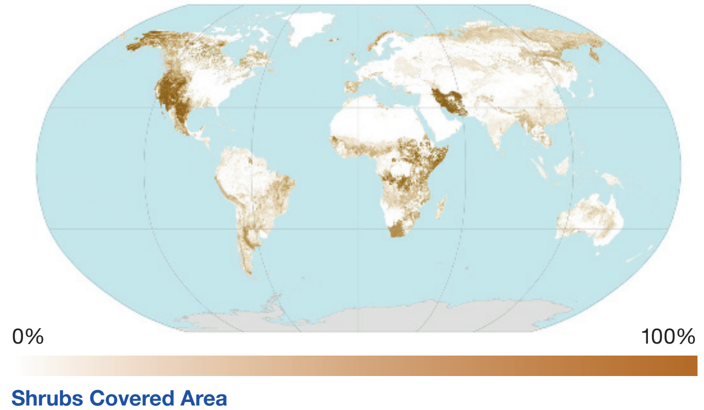
4.1.3 Global distribution of tree-covered areas is 27.7% of terrestrial land.

Shrub cover

Shrub-covered areas have a natural shrub cover of 10 per cent or more. It can include scattered trees if they cover less than 10 per cent of this land, and **herbaceous plants**. This category includes areas flooded by inland fresh water but not coastal salt or brackish water.

Shrubland is also called heathland or chaparral. Its diverse vegetation shares the characteristics of shrubs. Most shrubland is in warm temperate climates with mild, wet winters and hot, dry summers, including the Mediterranean, California USA, Chile, South Africa and southern Australia. Others occur in the semi-arid tropics and the Arctic with smaller pockets found elsewhere. Australia has the greatest expanse and range due to the dry variable climates (see Figure 4.1.4 and 4.1.5).

4.1.4 Scrubland in King's Canyon, NT



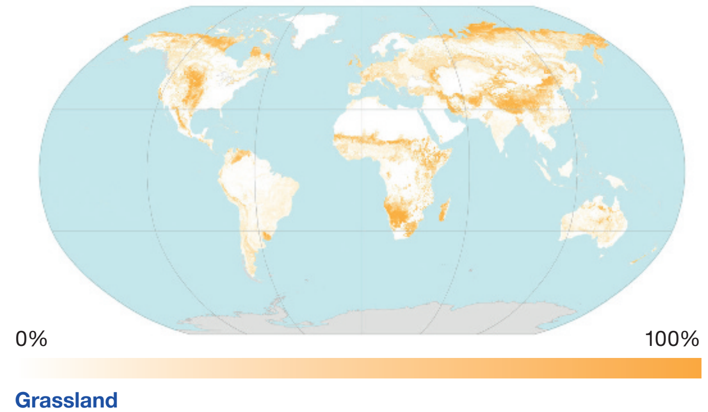
4.1.5 The global distribution of shrubland covers 9.5% of terrestrial land.

Grasslands

Grasslands have natural **herbaceous plants** covering 13 per cent of land area and include grasslands, prairies, steppes and savanna, irrespective of human or animal activities, such as grazing (See Figure 4.1.7). **Woody plants** (trees and shrubs) can be present if they cover less than 10 per cent.

The African savanna is dominated by grasses and dispersed trees and has a complex food web. It is hot, dry and prone to wildfires for half the year. A rainy season yields tall grasses for grazing herds like zebras and wildebeests, preyed on by carnivores such as lions and cheetahs (See Figure 4.1.6). The steppe grasslands stretch across Eurasia through to Mongolia into northeast China. Similar to savanna grasslands, they are typically drier and colder. Far from oceans with mountainous barriers, they lack humidity. Poor soil quality yields few other plants so the main vegetation is herbs and seas of grasses up to 66 centimetres tall.

4.1.6 Savanna grasslands of Namibia, Africa



4.1.7 The global distribution of grasslands covers 13% of terrestrial land.

Herbaceous freshwater wetlands

Herbaceous vegetation is any area where vegetation has a cover of 10 per cent or more that is regularly flooded by fresh or brackish water, such as swamps and marshes, for at least two months of the year. Woody vegetation may be present if its coverage is under 10 per cent. Herbaceous plants are non-woody and **vascular**, including grasses and grass-like plants. The Everglades of Florida, USA and the Okavango delta of Africa are examples (see Figures 4.1.8 and 4.1.9). Kakadu National Park's floodplains in the NT have herbaceous swamp vegetation dominating areas submerged for six to nine months a year. Waterlilies are common, such as the blue, yellow and white snowflake.

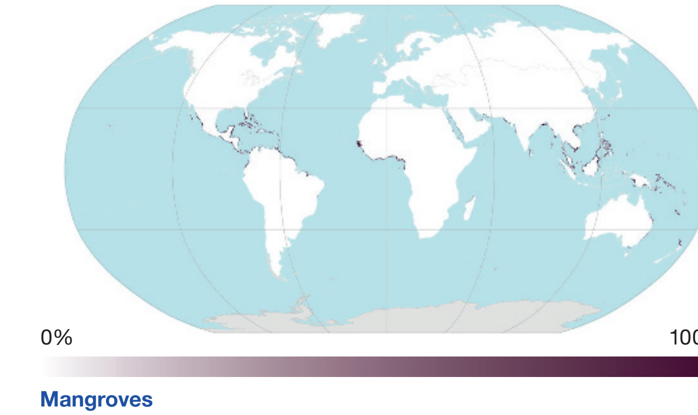
4.1.8 Herbaceous vegetation, Okavango Delta, Botswana, Africa

4.1.9 The global distribution of herbaceous vegetation covers 1.3% of terrestrial land.

Mangroves

Mangroves include any area with woody vegetation covering 10 per cent or more that is permanently or regularly flooded by salt and/or brackish water. They are found in coastal areas or deltas of rivers and provide important environmental services including their role as a 'carbon sink' (see the box, Spotlight: Australia's mangroves as 'carbon sinks'). See Figures 4.1.10 and 4.1.11.

4.1.10 Mangrove forest, Krabi, Thailand



4.1.11 The global distribution of mangroves covers 0.1% of terrestrial land

SPOTLIGHT

Australia's mangroves as a 'carbon sinks'

Australia's mangrove forests, tidal marshes and seagrass meadows absorb some 20 million tonnes of carbon dioxide annually, making them an important 'carbon sink'. They can absorb carbon dioxide up to 40 times faster than forests and have five times the storage capacity of land trees. Mangroves store carbon in their soils as well as in the plants which, undisturbed, can be locked away for millennia. They are crucial in protecting coastlines from erosion, as fish nurseries, and in filtering water to maintain water quality.

When damaged by storms, heatwaves, dredging or land clearing, their stored carbon dioxide is released back into the atmosphere. In Australia, this means around 3 million tonnes of carbon dioxide is released into the atmosphere annually. Globally, these ecosystems are being lost twice as fast as tropical rainforests despite being far smaller.

Australia's 25 760 km coastline represents 5–11 per cent of the world's 'blue carbon' locked up in mangroves, seagrasses and tidal marshes. These coastal ecosystems are calculated to store 4000–6300 million metric tonnes of carbon dioxide. A significant amount, compared to the annual carbon dioxide emissions—501.5 million tonnes in 2021.

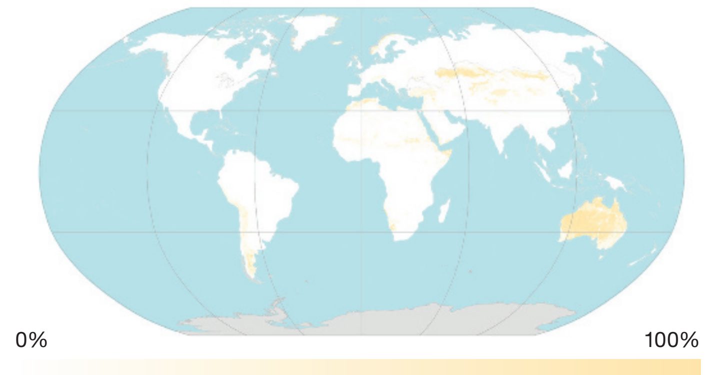
A record heatwave in 2015 along 1000 kilometres of the Gulf of Carpentaria's coastline induced mass mangrove dieback (see Figure 4.1.12). Recovery is slow with storm-damaged and dead mangroves stifling new growth. Significantly, these dead trees emit eight times as much methane (a powerful greenhouse gas) as live mangroves. In 2019, a cascade of rising sea levels, heatwaves and back-to-back tropical cyclones killed or damaged a 400-kilometre stretch of mangroves. Protecting these ecosystems is a vital contribution to slowing climate change.

4.1.12 Mass mangrove dieback in the Gulf of Carpentaria in 2015

Sparse vegetation

Sparse vegetation is land with 2–10 per cent natural vegetation coverage. It includes permanently or regularly flooded areas and deserts, except the very driest. Desert plants adapt to the coarse, dry conditions with extensive root systems, small leaves, stems that store water and prickly spines that discourage animals. Cacti in the deserts of North and South America are desert plants. In Australian deserts, the trees include the silvery white ghost gum, mulga, sandalwood, northern cypress pine, sandhill wattle and western myall. Some shrubs, grasses and wildflowers are spinifex, saltbush, Mitchell grass, Sturt's desert pea and kangaroo paw. See Figures 4.1.13 and 4.1.14.

4.1.13 Spinifex grasses in the Pilbara, WA

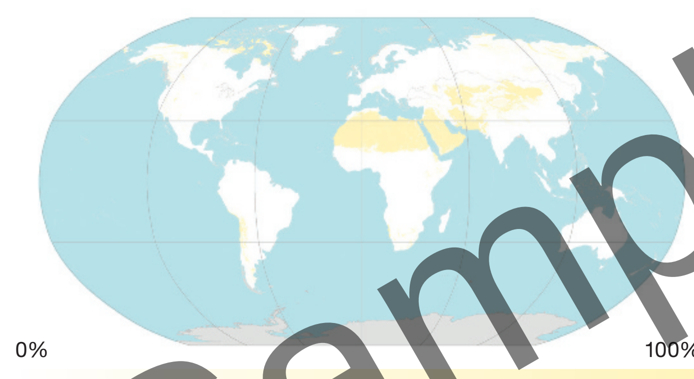


4.1.14 The global distribution of sparse vegetation covers 7.7% of terrestrial land.

Bare ground

Bare ground refers to land dominated by natural abiotic surfaces (e.g. bare soil, sand, rocks) with little to no natural vegetation cover (under 2 per cent). This includes areas periodically flooded by inland water (e.g. lake shores, riverbanks, salt flats). It excludes coastal areas affected by tidal saltwater. Deserts are good examples: the Sahara (Africa), the Gobi (Asia) and the Simpson (Australia), others are exposed rock surfaces, saltpans and areas covered with sand. See Figures 4.1.15 and 4.1.16.

4.1.15 Gobi Desert of remote Mongolia, a landscape devoid of vegetation

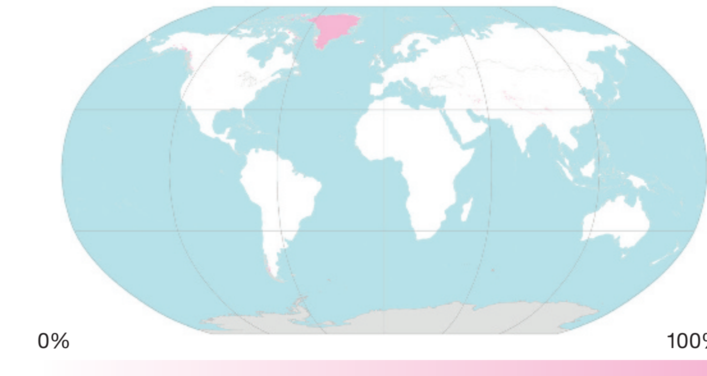


4.1.16 The global distribution of bare ground covers 15.2% of terrestrial land.

Snow and glaciers

Snow and glaciers include any area covered by snow or glaciers for at least 10 months of the year. The Antarctic ice sheet is Earth's largest single mass of ice, covering an area of almost 14 million square kilometres and containing 26.5 million cubic kilometres of ice. The ice sheet covers 98 per cent of the Antarctic continent. In Greenland, ice (sees Figure 4.1.17 and 4.1.18) occupies about 82 per cent of the island's surface, and if melted would cause sea levels to rise by 7.2 metres. Sea ice (an expanse of frozen seawater) covering the Arctic Sea reached its annual minimum extent of 4.67 million square kilometres on 18 September 2022, the tenth lowest reading in 40 years of satellite data collection. September Arctic Sea ice extent is now shrinking at a rate of 12.6% per decade, compared to its average extent from 1981 to 2010. Glaciers and ice sheets are detailed in Chapter 6.

4.1.17 Elephant Foot Glacier and icefield, North Greenland



4.1.18 The global distribution of glacier and ice fields covers 9.7% of terrestrial land.

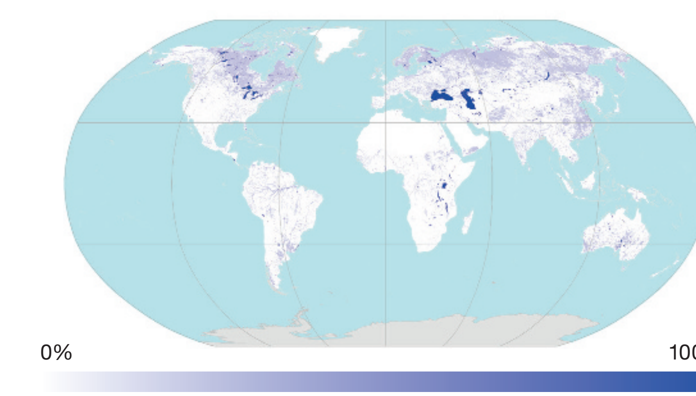
Water bodies

Any area covered by inland water for most of the year is called a water body (see Figure 4.1.20). Natural water bodies largely form by inland draining catchments, such as the Caspian Sea (the world's largest), North America's Great Lakes and Africa's Lake Victoria. Some water bodies can be frozen for up to 10 months of the year.

Artificial water bodies are engineered, mainly dams, which greatly impact freshwater ecosystems. Since the early 1980s around 180 000 square kilometres of land has been inundated by dam building. Dams fragment river systems, block animal migration routes and alter downstream flooding and sediment deposition patterns. Floodplains, riverbank zones and wetlands can be lost by building dams. Globally dam construction is booming, most intensely in India, China and Brazil. Zimbabwe's Kariba Dam has the world's biggest capacity (see Figure 4.1.19), forming Lake Kariba, 280 kilometres long and up to 32 kilometres wide. The storage capacity is 185 billion cubic metres and the surface area is 5580 square kilometres.

River diversions, wetland draining and excessive water extraction have led to surface water losses elsewhere. Any water surface imbalance is detrimental to the local biodiversity and ecosystems.

4.1.19 Kariba Dam lies in Kariba Gorge on the Zambezi River Basin between Zambia and Zimbabwe.



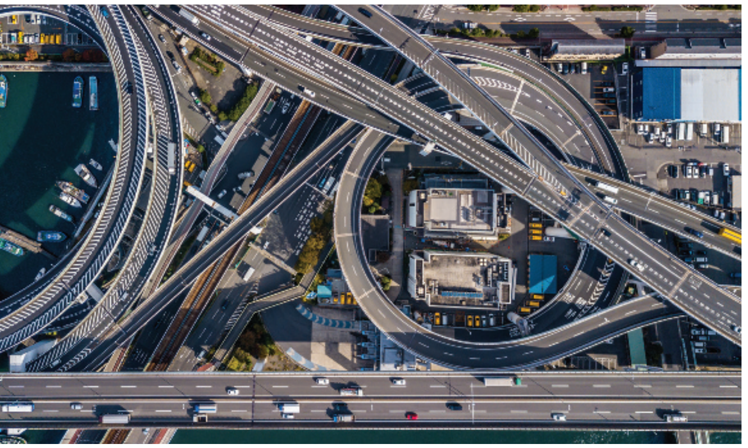
4.1.20 The global distribution of water bodies covers 2.6% of terrestrial land.

Artificial surfaces

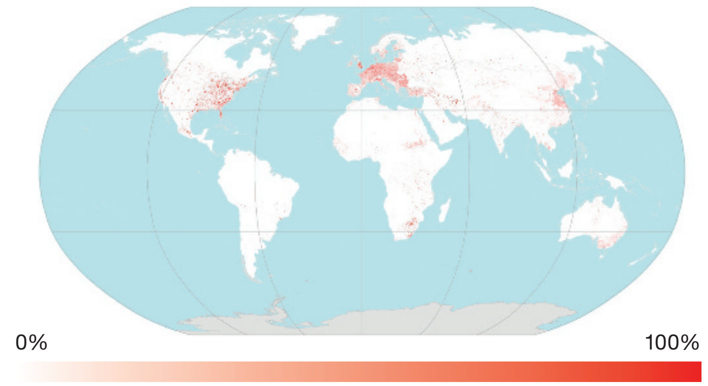
Artificial surfaces are urban areas or features such as parklands, sports facilities, industrial areas, waste dumps and mining sites. Urbanisation drives much land-cover change. Buildings and artificial surfaces (e.g. roadways and parking lots) contribute to ecosystem loss and natural **habitat fragmentation**. They often impact local tree-covered areas, grasslands or shrublands.

Soil sealing also causes loss. It adds a hard, impervious layer of concrete or asphalt (see Figure 4.1.21) which degrades the soil and increases flood risk. The soil's moisture content, its biodiversity and the amount of organic matter all decline. The nutrient cycle slows down, as does the soil's ability as a diluter of pollutants.

Some artificial surfaces are built on existing cropland. Such conversions are especially apparent in Japan, Switzerland and the Netherlands. See Figure 4.1.22.



4.1.21 Motorway interchange in Osaka, Japan



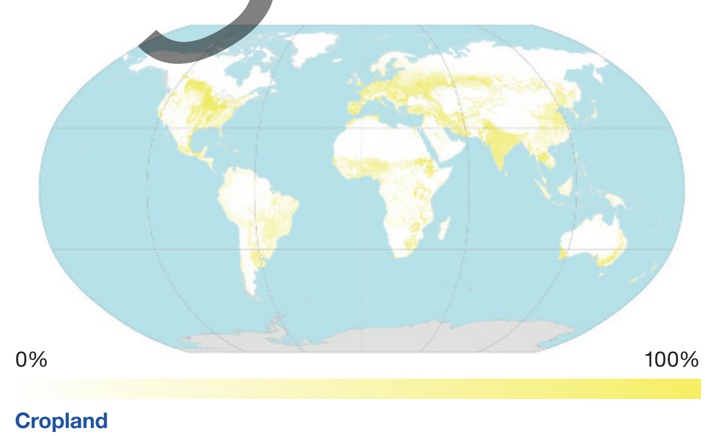
4.1.22 Global distribution of artificial surfaces covers 0.6% of terrestrial land.

Cropland

Crop land encompasses a wide range of crops, both herbaceous and woody. Herbaceous crops include wheat, rice, maize, soybean, barley, sorghum, cotton, sugar cane and hay plants (See Figure 2.1.23). Woody crop land cover features a layer of permanent crops. It includes orchards and plantations such as fruit trees, coffee and tea plantations, oil palms, and rubber plantations. In some areas, woody and herbaceous crops are layered. This is seen in Mediterranean regions when wheat is grown in olive tree groves.

Agricultural expansion drives natural and semi-natural land losses worldwide (See Figure 4.1.24). Rapid population growth and rising living standards are increasing this expansion. Natural vegetation is replaced with far fewer plant types, lowering a community's plant diversity. Converting natural landscapes to croplands requires significant effort and expertise. Fertilisers and pesticides are added to maintain productivity, but overuse can degrade soils, reduce biodiversity and deplete nutrients. Sustainable agricultural practices are critical to offset the environmental impacts of cropland.

4.1.23 Sugar cane cropland, Sao Paulo state, Brazil.



4.1.24 The global distribution of cropland covers 12.6% of terrestrial land.

Land use

Land use describes human activities such as agriculture, forestry and constructions that alter land-surface processes including hydrology and biodiversity. It is also defined by the land's social and economic purposes such as subsistence versus commercial agriculture or public versus privately owned land. Consider these differences between land cover and land use:

- Forests are classified as land use if they are used for selective logging or recreation (see Figures 4.1.25 and 4.1.26).
- A naturally occurring lake is land cover, but considered as land use when used for irrigation or recreation.
- Grasslands is a type of land cover, but when used for grazing sheep and cattle it is also considered a land use.
- The African savanna is land cover, but is classified as a land use if managed as a tourist safari park or wildlife refuge.

4.1.25 Pine forest is a land cover

Land cover change

Changes in land cover can be traced back many millennia and are a direct result of people's need for resources, especially food. Initially this involved using fire to corral game, but it accelerated once farming practices developed, escalating deforestation and transforming vast natural areas into agricultural landscapes. Industrialisation concentrated human populations in urban areas, a process called urbanisation. This led to an intensification of agriculture on productive lands and the abandonment of marginal land. Rural populations gradually declined.

SPOTLIGHT

Observing land cover change

While changes in land cover extent can be assessed using field-based observations or remote sensing, local expertise is often needed to identify different activities in various parts of a landscape. For example, a satellite image of a vegetated area may be undisturbed old-growth forest, a selectively logged forest, secondary regrowth or a rubber tree plantation. Only the expertise of local land managers can provide such information.

From 1700 to 2020, the world's population increased from 650 million to 7.6 billion. Roughly a quarter of Earth's land area changed from trees and shrubs to crops and pasture:

- forest and woodland declined from 41 to 31 per cent
- grassland and similar vegetation declined from 24 to 13 per cent
- shrubland declined from 6.5 to 2 per cent
- cropland expanded from 2 to 11 per cent
- pasture expanded from 4 to 23 per cent.

Land cover change is caused by both natural and human-related processes. While some parts of the world are marginally affected by land cover change, others have been transformed by human activity. In Australia's southern agricultural regions, up to 50 per cent of native forests and 65 per cent of native woodlands have been cleared or greatly modified. Even in areas where the type of land cover has not changed, it has been degraded by land use and management, such as using grasslands and shrublands for grazing livestock.

4.1.26 Rainforest being cleared in Borneo for oil palm plantations

Activities

Acquiring and processing geographical information

1. Distinguish between land cover and land use.
2. Outline the changes in land cover from a historical perspective.
3. State why expert knowledge is often required to supplement field-based observations and remote sensing when investigating the nature and extent of land cover change.
4. Outline the extent of land cover change in the 320 years from 1700 to 2020. To what extent does land clearing in Australia reflect this trend?

Applying and communicating geographical understanding

5. a Using the following data create a pie graph of the distribution of terrestrial land cover.

Tree cover: 27.7%	Shrubs: 9.5%	Herbaceous vegetation: 1.3%
Bare earth: 15.2%	Snow and ice: 9.7%	Artificial surfaces: 0.6%
Grasslands: 13.0%	Sparse vegetation: 7.7%	Mangroves: 0.1%
Croplands: 12.6%	Water bodies: 2.6%	

   b Identify the four largest terrestrial land cover types. Which are the smallest land cover types?
6. Study the information describing the various land cover types. Create a table to summarise it. Label the columns: Land cover type, Location, Characteristics. Label the rows: Tree cover, Shrub cover, Grassland, Herbaceous vegetation, Mangroves, Sparse vegetation, Bare earth, Snow and glaciers, Water bodies, Artificial surfaces, and Cropland.

UNIT 4.2

Land cover change: Natural causes

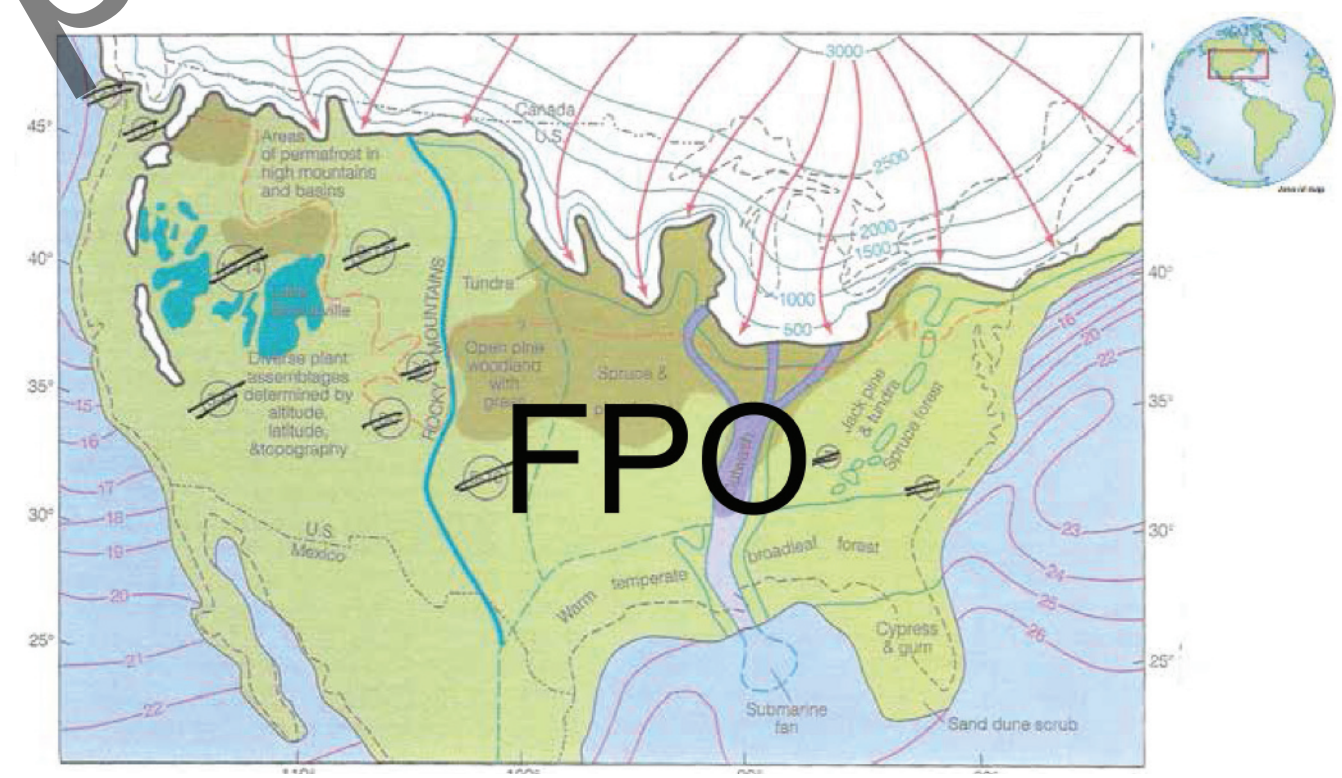
Changes in land cover can be initiated by a range of natural processes. These include non-**anthropogenic** climate change (see Chapter 13); geophysical processes including continental drift, earthquakes, volcanic eruptions and landslides; **plant succession**; and fire and pests.

Natural climate change

Earth's climate has changed over time. The last time the climate was markedly different from the present was during the last **glaciation** (or ice age). It reached its peak about 24 000 years ago, when ice and snow cover was much greater than it is today. This period of glaciation was the last in a long succession of glaciations that characterised the **Pleistocene**, a geological epoch from 2.6 million years ago to about 11 700 years ago.

During the last glaciation, the climate of the middle and high latitudes of the Northern Hemisphere cooled to such an extent that a vast ice sheet formed over central and eastern Canada and spread southwards into what is now the USA, and westwards towards the Rocky Mountains. It advanced at an average rate of 25 to 100 metres a year (see Figure 4.2.1).

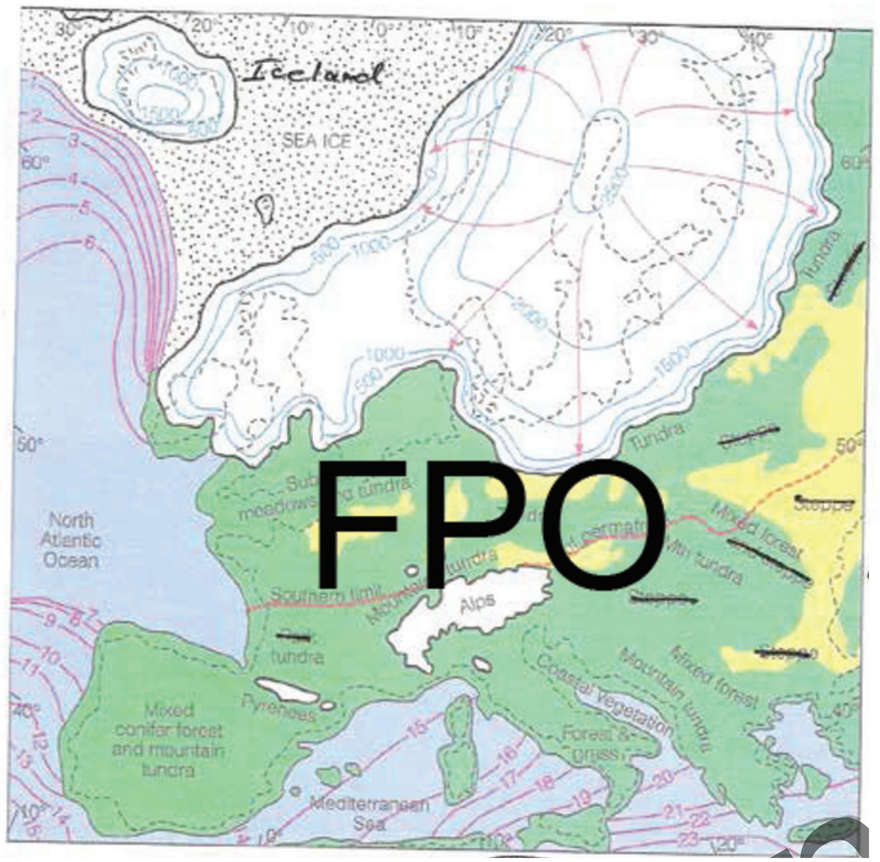
At the same time, another vast ice sheet formed over the mountains of western Canada, northern Europe and north-west Asia. Large glacier systems developed in the European Alps, the Andes, the Himalayas and the Rockies. Smaller glaciers developed in all other ranges and mountain peaks at all latitudes, including Tasmania and Australia's Southern Alps.



4.2.1 The geography of North America about 20 000 years ago, during the last glaciation. Sea levels were about 120 m lower exposing large areas of the continental shelf. The southern margin of the ice sheet, shown here, was over 2.5 km deep in the northern parts of the continent.

Areas of sea ice also expanded during periods of glaciation creating one vast northern glacial ice sheet that covered all of the Arctic and much of the sub-Arctic regions.

With the southwards advance of the northern ice sheets, the **periglacial** zones spread to lower latitudes and lower altitudes. In Russia, **permafrost** extended 1000 kilometres south of the ice sheet's edge. In North America, the periglacial zone was largely limited to a small belt adjacent to the southern edge of the ice sheet. For the southern extent of permafrost in North America and Eurasia, see Figures 4.2.1 and 4.2.2.



4.2.2 A vast periglacial zone separated the northern European ice sheet from the glacier-covered Alps.

The climate of the last millennium

The Middle Ages (fifth to the fourteenth centuries) saw a period of relatively mild climate followed by a period when average temperatures reduced by 1° to 2°C. It lowered Western Europe's snowline by about 100 metres, ushering in a period of glacial advance.

The Little Ice Age lasted from 1300 to 1870. Colder, snowier winters saw sea ice in the North Atlantic advancing south, and more frequent, violent storms. Grain crops failed to ripen in the cooler, wetter summers so famine was common. Life expectancy in England decreased by 10 years within a century. By the early seventeenth century, advancing glaciers invaded farmland in the Alps, Iceland and Scandinavia. By the nineteenth century, erratic weather conditions led to rising grain prices, epidemics and famines. This initiated large-scale migrations, notably to North America.

Mountain glaciers and North-Atlantic sea ice began to retreat with the general warming in the 1870s. It brought conditions favourable for crops in middle latitudes as the world's population was expanding rapidly.

Today's anthropogenic warming is significant for its accelerating rate. Climate changed very slowly in the past, over centuries. Today's rate is over decades. The retreat of glaciers, ice sheets and sea ice, and the associated sea-level rise, is changing the planet's land cover. It can be observed and measured using spatial technologies.

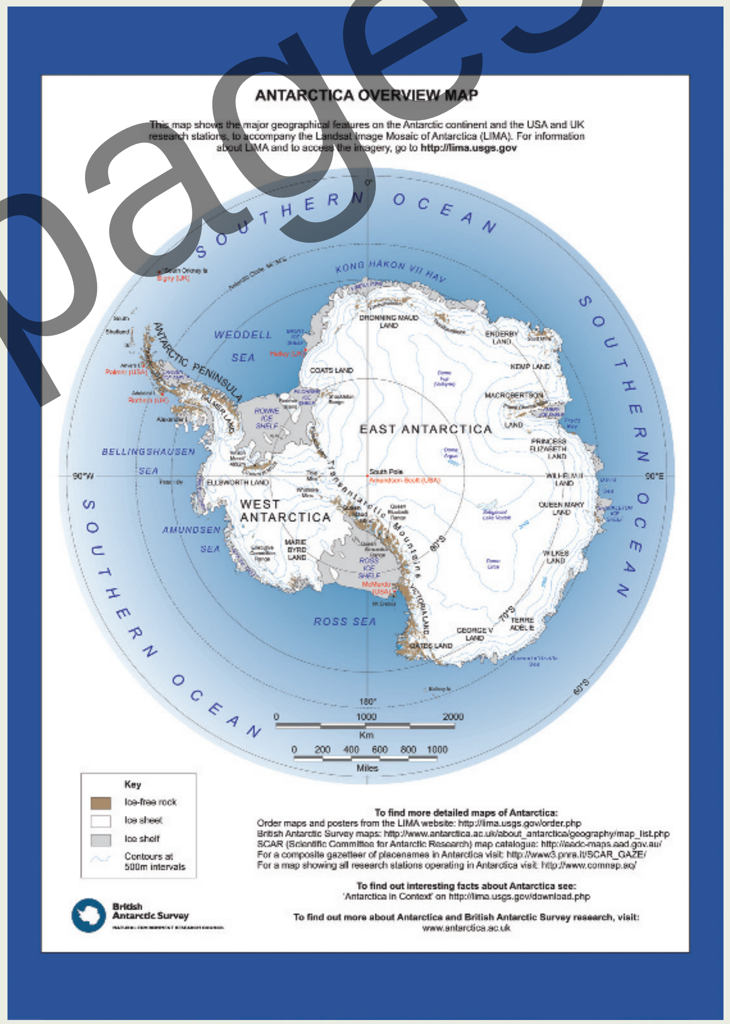
SPOTLIGHT

The Antarctic ice sheet

Antarctica is home to the larger of the Earth's two polar ice caps. The ice sheet covers 98 per cent of the Antarctic continent—almost 14 million square kilometres and contains 26.5 million cubic kilometres of ice. The ice sheet is up to four kilometres thick (see Figures 4.2.3 to 4.2.4). Roughly 61 per cent of Earth's freshwater is held in the Antarctic ice sheet.

This ice sheet is the focus of significant scientific attention. The melting Antarctic ice has added nearly three trillion tonnes of water to the oceans over the past 25 years, mostly from West Antarctica, where the rate of ice melting tripled—from 58 billion to 175 billion tons per year. Antarctic ice losses have led to sharply rising sea levels over the last decade.

If the entire Antarctic ice sheet was to melt, sea levels would rise about 58 metres. Even a 1-metre rise would degrade or destroy over a third of the world's coastal estuaries, wetlands, coral reefs and fertile river deltas. It would inundate low-lying countries such as Bangladesh and the island states of the Pacific and the Caribbean, and flood some of the world's largest cities, including Kolkata and Mumbai in India and Dhaka in Bangladesh.



4.2.3 Antarctica can be divided into West Antarctica, East Antarctica and the Antarctic Peninsula. The peninsula is home to scientific stations operated by many nations and a popular destination for cruise ship-based tourism. The numerous glaciers and floating ice shelves are changing rapidly here because this region is warming faster than the rest of Antarctica.

4.2.4 The Antarctic ice sheet

4.2.5 The Australian tectonic plate moves north by about 7 cm a year, the fastest on Earth.

Geophysical and geomorphological processes.

Geophysical and **geomorphological** processes such as **tectonics**, including earthquakes, volcanic activity and landslides, can initiate land cover change. Weathering, erosion and deposition also contribute.

Continental drift changed the distribution of the continents over tens of millions of years (detailed in Chapter 3). As landmasses traversed latitudinal zones they adjusted to new climatic conditions. Human activities including deforestation, urbanisation and agriculture can change land cover and significantly impact the environment.

Australia separated from Antarctica when the supercontinent Gondwana broke up 90 to 30 million years ago. As Australia moved north (see Figure 4.2.5) the climate became warmer and drier, transitioning the vegetation land cover from diverse forest to today's scrub and eucalypt landscape.

During the Pleistocene epoch, significant changes in sea level linked Australia to Indonesia and New Guinea via land bridges. This allowed new combinations of species and ecosystems as species dispersed and intermixed. Through isolation and time, Australia's flora and fauna evolved separately from other continents.

After separating from Antarctica, southern Australia contained diverse forests, their relatives are still living in small pockets. These rainforests became less diverse and more fragmented over time, their distribution becoming scattered before human occupation.

The mainland's characteristic aridity developed from about 20 million years ago. Recent cycles of increasing and decreasing aridity were part of the glacial cycles of the last million years or so.

There is evidence of regular fires in south-eastern Australia dating back 25 million years. Eucalyptus trees were absent from the forests, appearing on the east coast about 20–25 million years ago. While evidence suggests eucalypts appeared in response to more frequent fires, they were not common until 50 000–200 000 years ago. They responded positively to First Nations people's fire management practices.

Volcanic activity

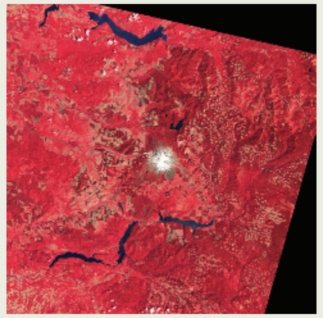
Volcanic activity can cause land cover change within the blast and deposition zone but a volcano's influence reaches far beyond its location. When widely distributed gases, dust and ash reach the upper atmosphere they upset its circulation patterns. Eruptions in the tropics can affect climate in both hemispheres while those at mid or high latitudes are usually limited to their own hemisphere. Massive eruptions throw gases and dust particles into the atmosphere which can block incoming solar radiation and cool the planet for months or even years. Sustained episodes can increase ice and snow cover extent causing vegetation pattern changes.

SPOTLIGHT

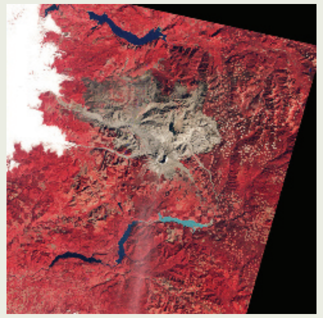
Mt St Helens

The 1980 eruption of Mt St Helens, USA, was the first observed in scientific detail. Satellite imagery revealed land cover changes and the rate of plant succession over the following decades. An earthquake followed, collapsing the northern face, causing the largest recorded landslide. Hot rocks, ash, gas and steam exploded upward and outward spreading volcanic debris (grey in images) over 600 square kilometres. Debris obliterated forest cover up to 27 kilometres away. The avalanche buried 23 kilometres of the North Fork Toutle River in rock and debris to an average of 46 metres deep. Volcanic mudflows (lahars) poured down rivers and gullies of the southern half of the mountain. Mt St Helens was reduced from 2950 metres to about 2550 metres. Eventually, the river carved a shallow, braided path through the buried valley.

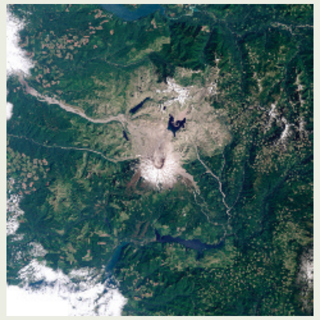
Heat and noxious gases sterilised the surface which became buried under ash, mud and rock. Nearly every living creature in the area perished, but traces of life survived—seeds, spores and fungi. Plant succession processes began and land cover was slowly re-established. (See Figures 4.2.6 to 4.2.9).



4.2.6 Mt St Helen's in 1979, before the eruption. Areas that appear red are vegetation.



4.2.7 Mt St Helens in 1980, immediately after the eruption. Areas that appear red are vegetation.



4.2.8 Mt St Helens in 2000

4.2.9 Mt St Helens in 2016

Weathering, erosion, transportation and deposition

The geomorphological process of weathering, erosion and deposition also impacts land cover. Typically, this impact is felt at a more localised scale than geophysical processes such as volcanic eruptions. These processes are detailed in Chapter 3.

4.2.10 Monument Valley, USA, is shaped by weathering, erosion, transportation and deposition.

Invasions and ecological succession

An invasive plant is a non-native species that spreads, causing habitat damage and threatening biological diversity. Such invasions typically occur when some, often human, intervention results in a loss of natural controls or the introduction of an exotic species, like blackberry.

Plant succession is the change in the types of plant species occupying a given area over time. It typically involves the processes of pioneering, establishing, sustaining and reproducing. It can also be described in terms of primary, secondary and climax plant communities. Beginning with a few pioneering species a community increasingly diversifies, then stabilises and self-perpetuates.

Plant succession may be initiated in two ways. Forming a new, unoccupied habitat, uninfluenced by pre-existing communities is called a **primary succession** (e.g. from a lava flow or landslide, or a disturbance like fire, strip mining or logging). **Secondary succession** follows the disruption of a pre-existing community. When succession results in a stable, self-perpetuating plant community it is called a **climax community**.

Fires and pests

Fire is a major threat to forests, shrublands and grasslands, changing the structure of habitats and the mix and diversity of species present. It impacts soil properties like texture, porosity, organic matter, nutrient availability and biota. This then impacts plant life. Drought, disease, insect infestation, overgrazing or a combination can intensify this impact. Uncontrolled animal populations such as rabbits can lay waste to communities like grasslands.

Pests threaten forests, shrublands and grasslands. Insect infestations can cause 'dieback' in forests, the progressive death of trees within a year or two after symptoms appear.

4.2.11 Clearing fungal-diseased common ash trees in the UK

Symptoms are often subtle, slow to develop and usually uniform throughout the tree's crown.

Trees and shrubs are also subject to diseases, extremely high or low temperatures, and fluctuations in soil moisture during long-term weather cycles. Weakened trees and shrubs are more susceptible to insect attack and fungal invasion. These include borer-type insects, canker diseases and fungi causing root rot.

In Europe, landscapes are transformed by a fungus (*Hymenoscyphus fraxineus*) that causes widespread dieback and a mortality rate of up to 85 per cent in ash tree forests. Most attempts to control its spread have failed, even removing trees in infected areas, as the fungus grows on forest leaf litter.

Tree root systems are especially vulnerable to soil environment changes. These include **soil compaction**, drainage pattern changes, excessive moisture, lack of water, removing or adding soil over the root system, and excess pesticide or fertiliser use.

Invasive animal species such as feral cats, foxes and cane toads can damage habitats. Without controls, rabbits and feral pigs can strip the vegetation exposing the soil to erosion. Some can kill native animal species and carp can increase the **turbidity** of waterways.

Activities

Acquiring and processing geographical information

1 State the relationship between climate and land cover.

2 When was Earth's climate markedly different from now? What was it like?

3 Identify the defining climatic event of the Pleistocene.

4 Outline the effects of the cooling associated with the last glaciation event. What was the impact on sea levels?

5 Identify the geophysical processes initiating land cover change.

6 Outline the role of fire in shaping land cover in Australia over time.

7 Outline the impacts of the Mt St Helens eruption on the surrounding area. What was the role of plant succession in repairing the damage?

8 Define plant succession. Outline the processes involved. Distinguish between primary and secondary succession. What is meant by the term climax community?

9 Outline the impacts of fire and out-of-control animal species on habitats.

10 Explain what dieback is. What are the likely causes?

Applying and communicating geographical understanding

11 Construct a flow diagram describing the nature of the world's climate over the past 1000 years. Use the following headings in your diagram:
- a Middle Ages
- b Little Ice Age (1300–1870)
- c Post–1870s

12 Study Figure 4.2.1. Using information from the map, write a brief report describing the nature and extent of the North American ice sheet and permafrost about 20 000 years ago.

13 Study Figure 4.2.2. Using information from the map, write a brief report describing the nature and extent of the European ice sheet and permafrost about 20 000 years ago.

14 Study Figures 4.2.3 and 4.2.4 and the related text.
- a Write one or two paragraphs describing the physical geography of the Antarctic ice sheet.
- b Outline the impacts of climate change on the ice sheet. State why any significant melting of the ice sheet would prove problematic.

15 Study Figure 4.2.5.
- a Describe Australia's progress northwards over the last 90 million years.
- b Briefly describe the relationship between continental drift and land cover change.

16 Study Figure 4.2.10. Working in groups, identify and describe the role of weathering and erosion in the formation of this landscape. Sketch the photo in and annotate the features, describing what agents of erosion appear to be primarily responsible for the formation of this landscape.

UNIT 4.3

Land cover change: Human causes

The human causes of land cover change include a rapidly growing population plus improvements in material standards of living, technological advances that greatly increased human capacity to transform landscapes and anthropogenic climate change (detailed in Chapter 13).

Population growth

The environment's ability to cope is threatened with becoming overwhelmed by a bigger population causing a rising demand for consumer goods, particularly from the developing world's rapidly growing middle-class. Increasing food and consumer goods adequately will hit growth limits. Already, the adverse impacts of production are evident and numerous. Demand for energy parallels production. It is largely sourced by burning fossil fuel-based commodities which have increased greenhouse-gas emissions. This has fuelled climate change which threatens entire ecosystems' stability.

Developed nations and a handful of rapidly developing nations currently account for just 18 per cent of the global population. The rest of the world's population (i.e. the remaining 82 per cent) aspire to the developed world's living standards. This is most apparent in the heavily populated parts of South and East Asia, especially China and India. The demands this will place on food and industrial production will deplete Earth's natural resources, especially soil and water resources. The biosphere will be seriously threatened. Species extinctions, largely a result of deforestation, will accelerate.

Technology

Advances in technology have greatly enhanced the ability of humans to transform Earth's terrestrial landscapes. Large-scale earth-moving equipment can change the topography and clear large areas of forest. Genetically modified crops have been developed to grow in areas once deemed marginal or unsuitable. Humans can build large dams and related water-distribution infrastructure to supply water to once-arid landscapes.

Examples of major dam infrastructure are:

Snowy Mountain Scheme, Australia: water is diverted from the Snowy River into the Murray and Murrumbidgee Rivers to expand irrigated crop production in an area once dominated by grazing.

State Water Project (SWP), USA: constructed in the 1960s and 1970s, it supplies water to over 27 million people and 750 000 acres of farmland. It is one of the world's most extensive systems of dams, reservoirs, power plants, pumping plants and aqueducts and is key to California's economy.

4.3.1 California's aqueducts demonstrate human capacity to transform land cover

Anthropogenic climate change

After nearly 1000 years of relatively stable climatic conditions with near-surface atmospheric temperatures fairly steady, global temperatures began to rise. Current climate changes since around 1975, along with projected changes, are many times faster than natural changes, which take place over hundreds or thousands of years.

Significantly, the world's leading scientific bodies including the UK's Royal Society, the US National Academy of Sciences, the US National Oceanic and Atmospheric Administration (NOAA), the US National Aeronautics and Space Administration (NASA), and Australia's CSIRO and Academy of Sciences, together with 97 per cent of the world's climate scientists, agree that:

- The world's climate is warming at an accelerating rate and is primarily caused by the burning of carbon-rich fossil fuels, which add carbon dioxide to the atmosphere. A secondary cause is the clearing of forests which take up carbon dioxide from the atmosphere.
- Climate change will continue to accelerate unless we act to reduce emissions. Such actions are possible and affordable and will result in significant improvements in people's health and the environment more generally. They will also boost economic activity. The sooner we act to reduce emissions, the lower the economic and environmental costs will be.

The consequences of global warming are mounting. Additionally:

- Atmospheric concentrations of carbon dioxide and other greenhouse gases that warm the atmosphere are rising rapidly. After remaining below 300 parts per million (ppm) for more than 400 years, atmospheric concentrations of carbon dioxide rose from 318 parts per million in 1960 to 421 parts per million in May 2022.
- In the Arctic, the extent of summer sea ice has been retreating since 1979. In 15 years (2007 to 2021) the Arctic recorded the lowest 15 minimum extents in sea ice in the 43-year satellite record.
- Almost all mountain, valley and piedmont glaciers, and most tidewater glaciers are retreating. Glacier National Park in the US, was home to 150 glaciers in 1910. It has since decreased to under 30 and most remaining have shrunk by two-thirds. Within 30 years most, if not all, the remaining glaciers will disappear.
- In Alaska, USA and Siberia, Russia, frozen ground (**permafrost**) is melting, releasing masses of carbon that have been locked away in the frozen soil for thousands of years. It also emits methane, another of the greenhouse gases. On entering the atmosphere, methane and carbon dioxide accelerate the rate of climate change, even as humans try to reduce their reliance on fossil fuels.
- Sea levels are rising at an accelerating rate. This rise is driven by the expansion of the ocean water as its temperature increases and increasing run-off from land-based ice (glaciers and ice sheets). Sea levels may rise by up to 1.3 metres by the end of the century.

Chapter 13 covers more on climate change.

● SPOTLIGHT

Australia burns

The 2019–20 Australian bushfire season, arguably the most devastating in Australian history, started with a series of uncontrolled fires in June 2019. Given the prolonged drought affecting New South Wales and much of Queensland, the blazes proved difficult to control. Many burned well into February 2020. Record high temperatures and strong winds were all that were needed to create catastrophic fire conditions.

By the time the fire crisis peaked, an estimated 18.6 million hectares (186 000 square kilometres) had been burned, over 5900 buildings (including 2779 homes) had been destroyed, and at least 33 people had been killed. The extent of habitat destruction was alarming. An estimated one billion animals were killed, and some endangered species were driven to the brink of extinction.

These bushfires emitted 400 megatonnes of carbon dioxide into the atmosphere, as much as Australia's average annual carbon dioxide emissions, in three months. These contributed to global warming, which heightens the likelihood of recurring megafires that will release yet more emissions. Scientists call this a climate **feedback loop**.

The fires became the centre of a public debate about the relationship between climate change and the growing incidence and severity of fire and drought in Australia.

The prolonged period of drought was followed by well-above-average rainfall caused by the occurrence of two major weather patterns—La Niña in the Pacific and the negative Indian Ocean Dipole—along with warmer than average waters around northern Australia. Flooding was widespread in south-eastern Australia and South East Queensland in early and late 2022. The Bureau of Meteorology links Australia's wild temperature and rainfall variability to global warming caused by human activities.

Activities

Acquiring and processing geographical information

1 Briefly outline how humans have impacted the nature and rate of land cover change.

2 Describe how population changes impact food and energy demands. How will growing standards of living in developing countries impact Earth and its resources?

3 Outline the key elements of the scientific consensus about the nature and causes of climate change.

4 Outline the evidence to support the claims made about anthropogenic climate change.

Applying and communicating geographical understanding

5 As a class, brainstorm examples of the way humans, via advances in technology, have been able to transform terrestrial land cover.

6 Study the box, Spotlight: Australia burns and then answer the following questions:

   a What factors fuelled the devastating bushfires?

   b What was the impact of the fires?

   c How did it impact the public debate surrounding the link between climate change and the incidence and intensity of bushfires?

Did You Know

The decade 2011–2020 was the hottest ever recorded on Earth. It had eight of the 10 hottest years on record. The other years in the top 10 were 2005 and 1998.

Earth is now about 1.2°C hotter than it was at the beginning of the industrial age in the mid-to-late-1800s. This number is important because in 2015 global leaders adopted a goal of preventing 1.5°C of warming since the rise of big industry.

UNIT 4.4

Impacts of land cover change

Land cover change is amplified by land clearing. Marginal land is often cleared for agriculture and food production while fertile land and valuable habitat are lost to urban expansion, industry and transport infrastructure. As the world population grows, the land-clearing rate escalates.

Impacts on ecosystem services

The clearing of natural vegetation causes a range of environmental impacts:

- **Change in radiation balance:** cleared land has a higher **albedo** than vegetated land.
- **Decline in soil water-holding capacity:** soil porosity and its water-holding capacity are reduced by clearing natural vegetation for agriculture. Soil compaction by grazing livestock often results. This raises the risk of **hydrologic drought,** especially during dry seasons. Exposed soils are susceptible to erosion during heavy rainfall. Soil erosion greatly impacts agriculture, local economies and ecosystems.
- **Decline in precipitation:** the cloud formation rate declines when forests are cleared for agriculture because the rate of **evapotranspiration** declines.

Anthropogenic changes in the landscape contribute to regional and global climate change. While not fully understood, converting forested land to agricultural land changes local climates by changing the radiation and water balance. Changes in precipitation and temperature patterns eventually harm the sustainability of agricultural systems.

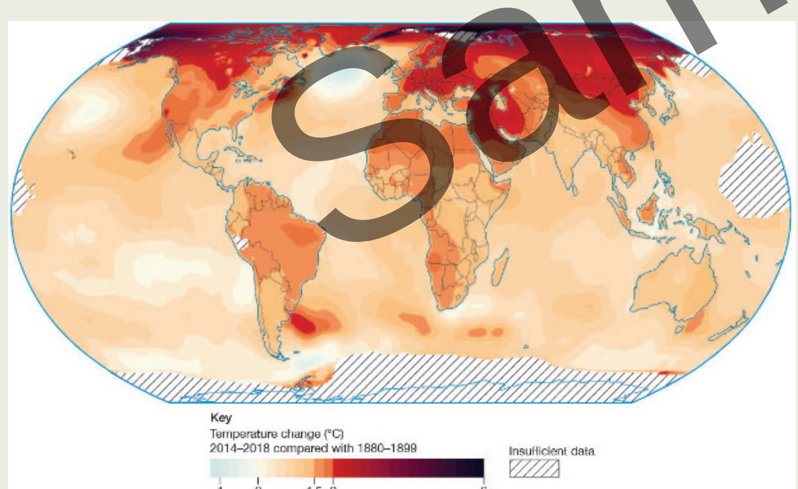
● **SPOTLIGHT**

Land cover change and a warming planet

Land-cover change releases greenhouse gases into the atmosphere, contributing to climate change (see Figure 4.4.1). Deforestation, especially combined with tillage-based agriculture, releases carbon dioxide.

Altered surface hydrology increases methane emissions (e.g. through wetland drainage and the flooding of rice paddy fields) as does cattle farming. Agricultural products increase nitrous oxide emissions (e.g. in organic nitrogen fertilisers, irrigation and biomass combustion).

While the complex relationship between greenhouse gas emissions and land-cover changes is not fully understood, it is known that land-cover change and land use accounts for about 12.5 per cent of human carbon emissions. An added uncertainty is how much sulphur dioxide and particulates (produced by biomass combustion) might contribute to regional and global cooling. As airborne particulates, they reflect incoming sunlight and this might affect cloud cover.



4.4.1 Temperature change 2014–18 compared to 1880–1899. The Arctic region has warmed more markedly than elsewhere, driving the decline in sea ice and retreat in terrestrial ice sheets and glaciers.

Land cover change and biodiversity

Clearing forests and grasslands for agriculture reduces biodiversity. Species loss is immediate and often complete; even partial forest habitat loss has an impact. When existing habitats are fragmented (see Figure 4.4.2) the forest's edges become exposed to external influences. This reduces the extent—and environmental integrity—of core habitat areas. Smaller habitat areas typically support fewer species. For any species needing undisturbed core habitat, habitat fragmentation can result in their extinction. By clearing land, an area becomes exposed to invasion by exotic (non-native) plants, animals and diseases, especially in remnants near human populations.

4.4.2 Fragmented boreal forests in Ontario, Canada

Land cover change and pollution

Removing land cover vegetation can cause water, soil and air pollution. Soil becomes exposed to water and wind erosion which ultimately reduces its fertility, especially when fire or large-scale machinery is used. Erosion releases phosphorus, nitrogen and sediments into streams and other aquatic ecosystems, increasing sedimentation, turbidity and **eutrophication**. The latter can trigger aquatic plant growth which depletes dissolved oxygen.

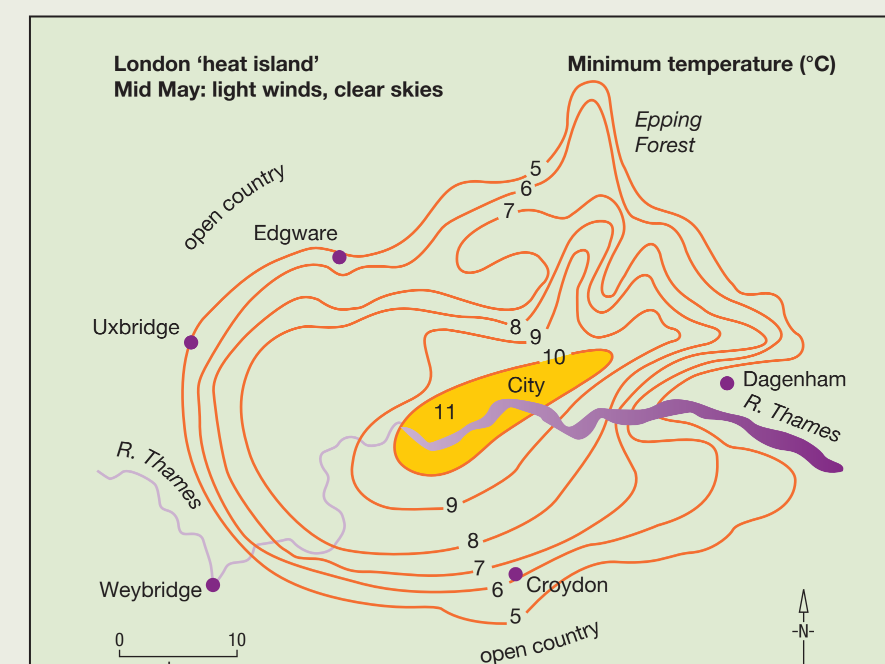
Modern agricultural practices can result in waterway and groundwater pollution (e.g. nitrogen and phosphorus fertilisers and concentrated livestock feedlots). This can cause **algal bloom** outbreaks in waterways that deplete oxygen levels. Some of these rapidly accumulating algae contain toxins that kill fish and harm livestock and native fauna. (See Unit 3.8.)

Modern agricultural practices can cause chemicals like herbicides and pesticides to accumulate in ground and surface-water bodies. They can accumulate in living things, be passed up the food chain and result in **bioaccumulation**.

Burning vegetation to clear land for agriculture is a major contributor to air pollution. Mining has a greater impact and when poorly managed can pollute waterways and groundwater with toxic metals.

Land cover change in urban areas

Urban expansion radically transforms land cover. Natural vegetation and farmland are replaced with built environments such as housing, factories and roads. This creates urban heat islands, making cities typically hotter. This can be caused by dark surfaces, like asphalt and roof tiles, absorbing and storing more solar energy than grass and trees; industrial processes and transportation



4.4.3 London's heat island effect

generating heat, and eliminating shade and transpiration by removing vegetation.

On average, cities are 1.5°–2.0°C warmer than surrounded vegetated lands. Planting street trees and creating parklands mitigates this because parks are cooler than their surrounding area. Shady trees prevent ground surface overheating and evapotranspiration pleasantly cools the air beneath the canopy. Plants transpire water into the atmosphere which evaporates to cool the atmosphere around its aerial parts. The effect is more pronounced at night. The park's size and plant community dictate the intensity and impact of this phenomenon. Figure 4.4.3 illustrates the **heat island** of London.

Urban run-off is a source of environmental pollution in aquatic environments. It is often heavily contaminated with oils and other pollutants from streets and cars.

Activities

Acquiring and processing geographical information

1 Outline the impact of land cover change has on:
   a radiation
   b the soil's water-holding capacity
   c precipitation
   d climate change
2 State the percentage of anthropogenic carbon emissions linked to land cover change.
3 Explain how the release of sulphur dioxide and particulates complicates the analysis of the effects of anthropogenic climate change.
4 Outline the impact of land cover change on biodiversity. Why is habitat fragmentation considered such a problem?
5 Identify the types of pollution associated with land cover change.
6 Outline the causes and impacts of algal blooms.

Applying and communicating geographical understanding

7 Study Figure 4.4.1. Write a paragraph outlining the global pattern of warming.
8 Write a paragraph or two explaining why urban areas are measurably warmer than their surroundings.
9 Study Figure 4.4.3. Use data from the map to describe the heat island effect associated with London.
10 As a class, brainstorm the strategies authorities could initiate to mitigate the effects of the heat island effect.

APPLICATION AND CONSOLIDATION TASKS

Task 1: Interpreting memes

A meme is an image, video or piece of text, generally humorous, that is copied and spread rapidly by internet users. Memes are often used by both private and public organisations to spread messages. Memes have been used during political campaigns successfully to discredit ideas or cast them into doubt. Being able to read or interpret a meme is an important life skill. It is also important to identify the issues being addressed, the techniques being used and where the meme originated.

- Where did you see the meme?
- Who sent you the meme or where did it originate?
- What is the meme about? Why?
- What can you see in the meme? What words, if any, are used?
- What events provided the background or context in which the meme was created?
- Has the creator used symbolism, irony, analogy or exaggeration to help communicate their message?
- Can you identify the perspective or point of view of the creator?
- Is the meme persuasive? If so, why?
- What alternative perspectives or points of view are there about this issue?

Continued from page 3.

Chapter glossary

soil compaction the increased density of soil when it is compressed by the trampling of livestock. The compression forces air and water from the soil

tectonic (processes) disturbances in Earth's crust that result from Earth's internal energy and create physical features, such as mountains, on Earth's surface

vascular related to, or having, vessels or ducts that convey fluids like blood or sap

woody plants plants that have a hard stem or trunk of wood