2

How climate change affects the natural world and human beings

Can we adapt to the inevitable consequences of climate change?

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Everything in nature is interconnected. Even a small change in one part of the natural world leads to changes in many others. So, as the temperature on the planet rises, we are seeing many other related changes. The level of the world ocean is rising, glaciers and permafrost are melting, the frequency and power of extreme weather events (heatwaves, hurricanes, storms, floods, and droughts) are increasing year by year. New and dangerous infectious diseases and various pests are appearing in places where they were so far unknown. These and other effects of climate change are dangerous to plants and animals, which cannot adapt quickly to such drastic changes. They also cause enormous economic damage and present a threat to human health and even human life.

The recent findings of the IPCC AR6 show that climate change could lead to even more dangerous consequences for people and for the natural world in the future. The scientists concluded that for every 0.1°C that the planet gets hotter, the impacts get worse, and risks get higher (Fig. 2.1). This is why United Nations Secretary-General António Guterres called this report 'a code red for humanity'. But on the flip side, every 0.1°C that's prevented can be crucial in limiting the extent of future damage.

Increased risks with rising temperatures assessed by the IPCC (Fig 2.2) show that even limiting global temperature rise to 1.5°C is not safe for all. At this level of warming, for example, 950 million people across the world's drylands will experience water stress, heat stress and desertification, while the share of the global population exposed to flooding will rise by 24%.

Figure 2.1

The negative impacts of climate change on the environment and human beings by the end of the 21st century, unless we do all we can to reduce greenhouse gas emissions

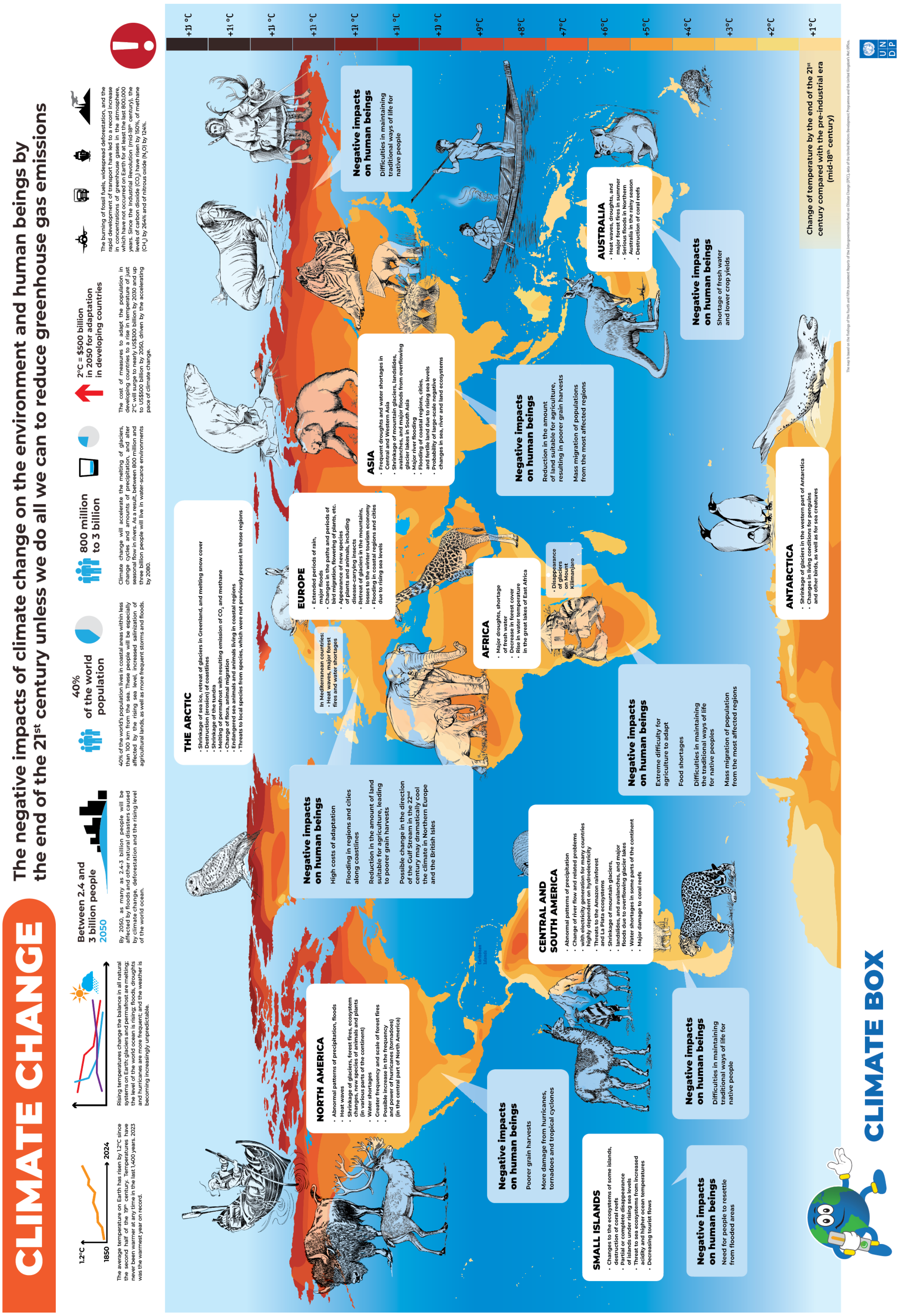
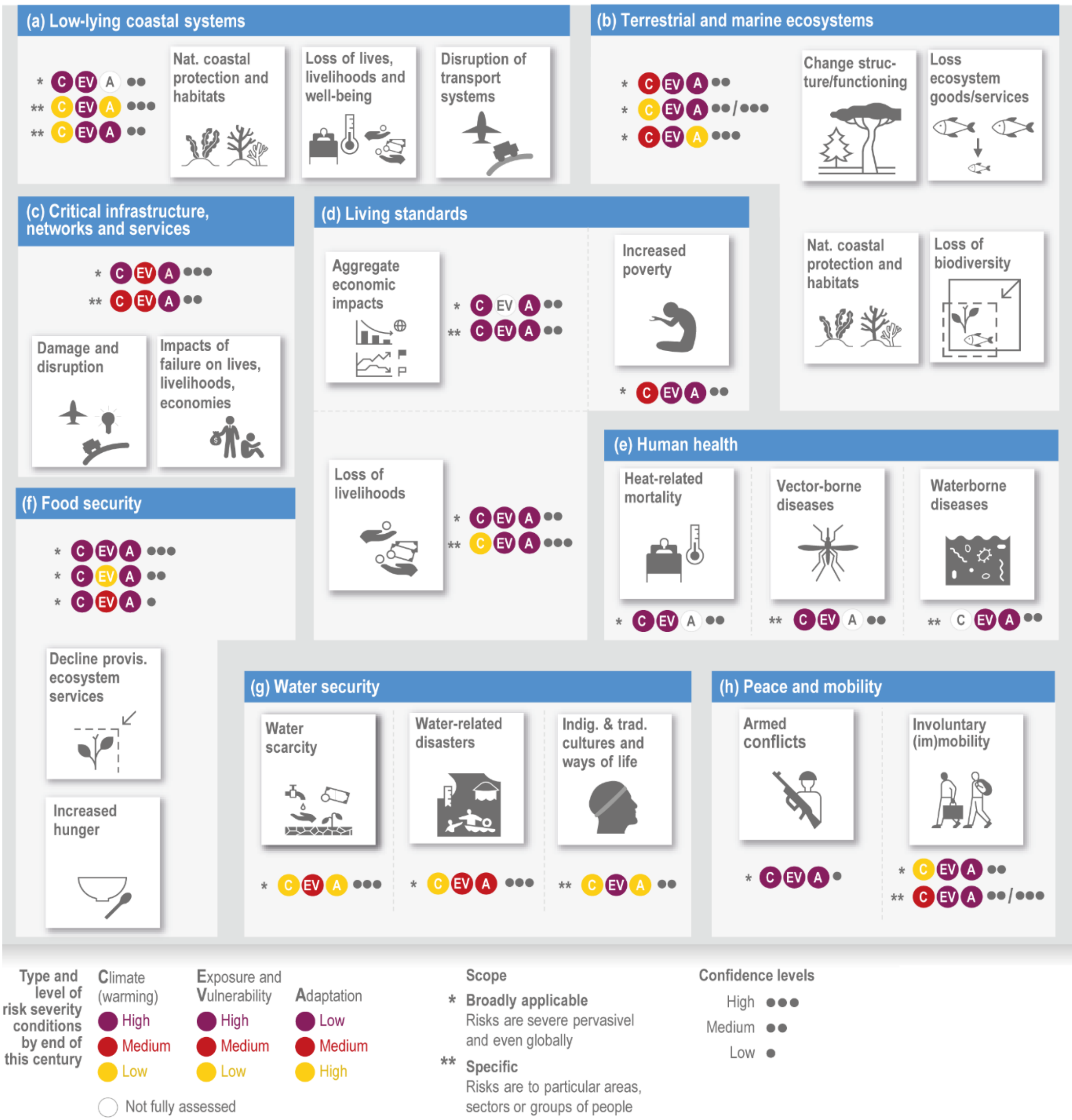


Figure 2.2 Comparing risks at different temperature levels on human and natural systems

	1.5°C	2°C	3°C	1.5°C vs 2°C	1.5°C vs 3°C
BIODIVERSITY LOSS Maximum percentage of species at high risk of extinction across forests and land	14%	18%	29%	1.3x WORSE	2.1x WORSE
DROUGHT Dryland population exposed to water stress, heat stress and desertification	0.95B PEOPLE	1.15B PEOPLE	1.29B PEOPLE	200M MORE PEOPLE	340M MORE PEOPLE
FOOD SECURITY Costs for adaptation and residual damage to major crops	$63 BILLION US	$80 BILLION US	$128 BILLION US	$17B MORE	$65B MORE
FIRES Increases in burnt area across Mediterranean Europe	40-54%	62-87%	96-187%	1.6x WORSE	3x WORSE
EXTREME HEAT Increase in number of days per year with a maximum temperature above 35°C (95°F)	45-58	52-68	66-87	1.2x WORSE	1.5x WORSE
EXTREME HEAT Increase in annual number of heatwaves in Southern Africa	2-4 TIMES	4-8 TIMES	8-12 TIMES	2x WORSE	3.3x WORSE
SEA LEVEL RISE Global mean sea level rise by 2100	0.28-0.55m	0.33-0.61m	0.44-0.76m	1.1x WORSE	1.4x WORSE
FLOODS Increase in global population exposed to flooding	24%	30%	NO DATA AVAILABLE	1.3x WORSE	NO DATA AVAILABLE
CORAL REEFS Further decline in coral reefs	70-90%	99%	NO DATA AVAILABLE	1.2x WORSE	NO DATA AVAILABLE

Today's climate change will indeed reduce agricultural productivity, limit the availability of freshwater, increase the severity of droughts, heat waves and tropical cyclones, and reshape coastal environments on a speed and scale that could provoke destabilizing societal responses. The WMO established that four key climate change indicators – greenhouse gas concentrations, sea level rise, ocean heat and ocean acidification – set new records in 2022. This is yet another clear sign that human activities are causing planetary-scale changes on land, in the ocean, and in the atmosphere, with dramatic and long-lasting ramifications. Unless we do all we can to reduce greenhouse gas emissions, the negative impacts of climate change on the environment and human beings could well be irreversible by the end of the 21st century (Fig. 2.3).

Figure 2.3 Key risks to natural and human systems stemming from climate change by the end of the century



Experiences suggest that exploring the resilience of past populations to climatic changes and anomalies could provide key insights into valuable solutions on how to cope with climate change today and in the future. To reduce the damage caused by climate change, humanity must take appropriate measures, especially by building resilience to the human-caused warming that is already baked into the current climate crisis. The evidence from impacts so far and projected risks show that worldwide climate-resilient development action is more urgent than now than ever before.

Feasible and effective adaptation measures are presented for each of the themes discussed in this chapter. They include measures which can reduce risk, such as considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure. They also include measures which can help to safeguard biodiversity and ecosystems that are critical for climate-resilient development, given the threats climate change poses to them and their roles in adaptation and mitigation (Fig. 2.4).

While we all feel the impacts from climate change already, they most hit the poorer, historically marginalized communities. Scientists noted in the IPCC AR6 report that today, between 3.3 billion and 3.6 billion people live in countries highly vulnerable to climate impacts, mostly in the Arctic, Central and South America, Small Island Developing States, South Asia and much of sub-Saharan Africa. Climate change impacts exacerbate existing conflicts, inequalities, conflict, and development challenges (e.g., poverty and limited access to basic services like clean water) across many countries in these regions, and limit communities' capacity to adapt. For instance, from 2010 to 2020, mortality from storms, floods and droughts was 15 times higher in countries with high vulnerability to climate change than in those with very low vulnerability.

This section explores the impacts of climate change on various regions, societies, and economic activities, and presents examples of climate adaptation measures that help mitigate and prepare for some unavoidable negative climate impacts.

Climate change-related hazards, risks, impacts, resilience and adaptation

Today, the Intergovernmental Panel on Climate Change (IPCC) uses the term **resilience** to mean the ability of coupled human and natural systems 'to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure.'

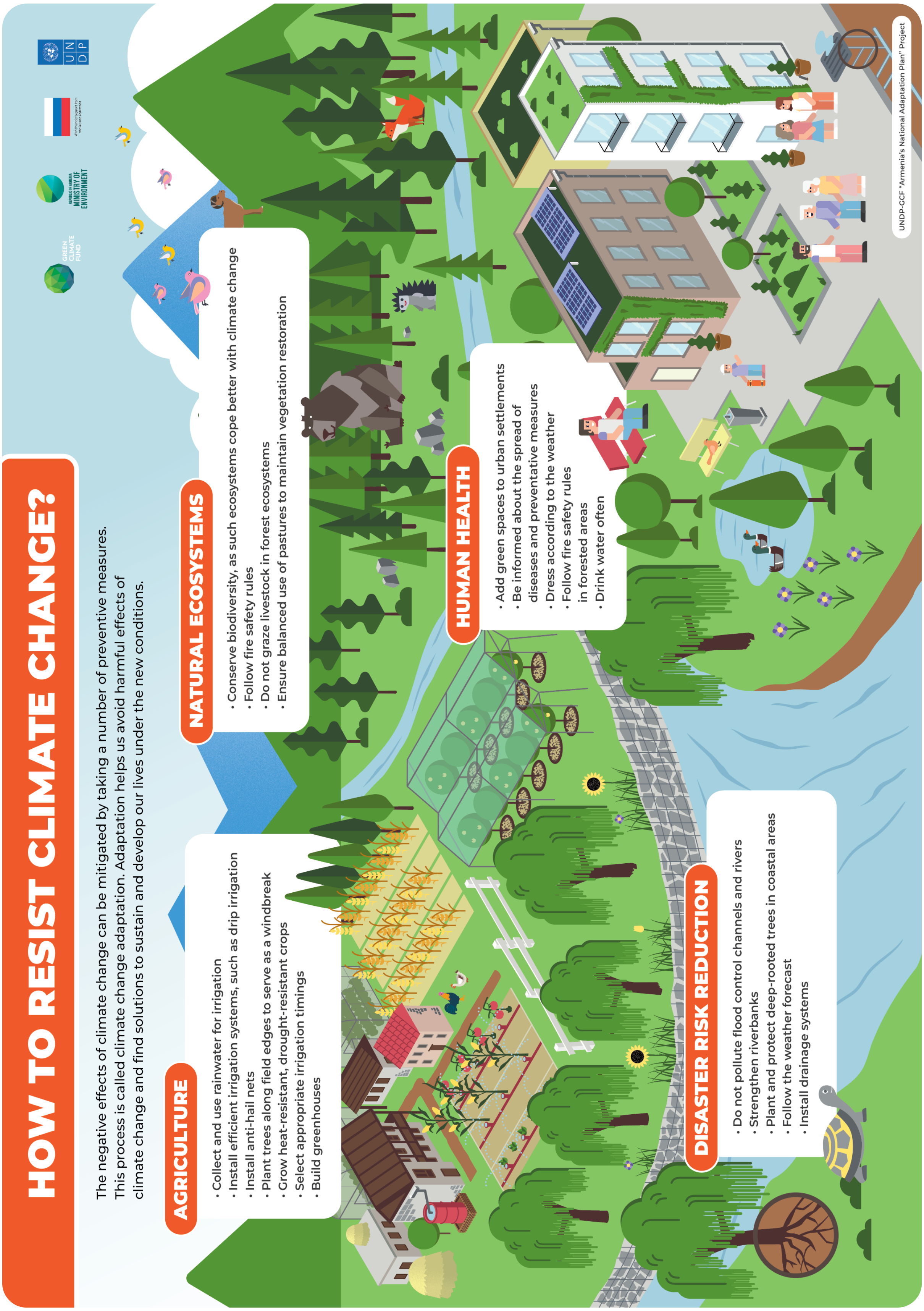
It therefore encompasses **adaptation**, which the IPCC defines as the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. For example, adaptation measures might include the construction of buildings that are more resistant to extreme weather events, building dams to combat floods, developing new, drought-resistant crop varieties, etc.

The IPCC also widely uses the concept of **risks** in relation to the potential for adverse consequences from climate change for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change.

The consequences of realized risks from climate change on natural and human systems define the **impacts**. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure.

Hazards are defined as negative impacts from natural or human-induced physical events or trends that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

Figure 2.4 How to adapt to climate change and build resilience



2.1 How climate change affects **the weather**

Scientists have noted that during the past 50 years the weather around the world has become much more extreme. We hear from time to time of yet another natural disaster: a devastating hurricane in the Philippines, an unprecedented drought in Australia, severe floods in Europe, excessive forest fires due to prolonged heat waves and droughts in Canada, Greece and Hawaii, and snowfall in Cairo and Alexandria, Egypt, for the first time in a century. Every day the temperature hits new records: in Europe we experience exceptionally hot summers, and winter temperatures that plunge suddenly from above zero to -20°C.

Scientists refer to such freak weather conditions as weather anomalies. For example, unusually cold periods in the summer or a prolonged thaw during the winter are the most common weather anomalies in areas with temperate climates in the northern hemisphere. When weather anomalies pose a threat to the health, lives, and economic activity of people, they are **extreme weather phenomena**.

Weather anomalies are any deviation from the 'usual' weather in a particular season, month, or day, where 'usual' is to be understood as the average state of the weather in that region during a specific past period, most usually 1961–1990.

Extreme weather (meteorological) phenomena are natural processes and events associated with weather conditions that arise in the atmosphere, or on inland or ocean waters, the effects of which can lead to the destruction of people, animals, and plants, and can cause serious damage to the economy.

Extreme weather events include prolonged heat or extreme cold, very strong wind, hurricanes, tropical storms (typhoons), dust storms, heavy rain, heavy snow, whirlwinds or tornadoes, floods, droughts, avalanches, landslides, and many others.

Note: earthquakes, volcanic eruptions and tsunamis are not dependent on climate and weather, so they are not WEATHER phenomena!

Figure 2.1.1 **December rain instead of snow in Moscow is no longer a rarity**

Severe sand and dust storms in the Middle East in 2022

Severe sand and dust storms are defined as storms caused by intense winds over areas of arid soil that pick up large amounts of ground material in the atmosphere. Approximately two tonnes of sand and dust enter the atmosphere each year, according to the United Nations Coalition to Combat Desertification. Sand and dust storms occur most frequently over deserts and regions with dry soil. In the Middle East and other arid regions, they can come in two forms. **Haboobs** (Arabic for 'violent wind') come from storm fronts and often appear as walls of sand and dust marching across the landscape. But like thunderstorms, haboobs don't last long. Then there are the long-lived, wide-reaching dust storms that can last for days. In Iraq, such storms are often associated with the persistent north-westerly winds, called **shamal** (Arabic for North). The construction of more dams, mismanagement of water, extreme dryness, desertification, and other factors all contribute to this nightmarish phenomenon.

In April and June 2022, Iraq and other countries in the Persian Gulf were looking up at an apocalyptic orange sky with a flurry of sand and dust storms. There were reports of port, airport, road and school closures, and flight cancellations. The storm sent thousands of people to hospitals with breathing problems. Dust storms can be especially dangerous for people with asthma; besides, they can transport disease microbes. Dust storms also cause loss of soil, especially its nutrient-rich lightest particles, thereby reducing agricultural productivity.

In recent years, sand and dust storms have become more common in the Middle East and other arid parts of the world, such as North Africa, Northern China, Mongolia and Kazakhstan, Australia, as well as central United States. In Mauritania, where the Sahara Desert covers 90% of the territory, there were just two dust storms a year in the early 1960s, but there are about 80 a year today, according to experts at Oxford University.

Scientists say that more frequent dust storms result from poor farming practices, including overgrazing and ripping up the biological crust, as well as climate change and associated increases in global and local temperatures and droughts. It is now established that sand and dust storms are a global phenomenon that affect our economies, health, and environment, and not just in the drylands. This phenomenon impacts everyone – men, women, boys, and girls – but not all in the same way. The differences stem from gender-based roles in the productive, economic, family and social spheres. Furthermore, sand and dust storms can be life-threatening for individuals with adverse health conditions. They are directly related to land degradation and can be addressed through sustainable land management and by achieving land degradation neutrality.

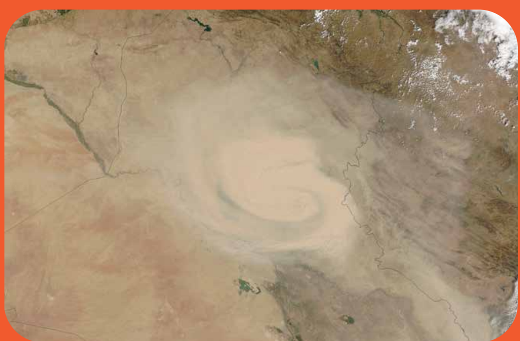


Figure 2.1.2

Satellite image of a dust storm in Iraq on 7 and 9 April 2022

So, what is happening to the weather and what does climate change have to do with it?

Observations suggest that the number of odd weather patterns and extreme weather events is increasing steadily all around the world. Scientists believe that this may be linked with global climate change. As the average temperature on the planet rises, the evaporation of water from oceans, lakes and rivers increases. This in turn increases the amount of moisture in the atmosphere, which leads to heavy rain in some areas. Also, higher temperatures in the surface waters of oceans are causing highly dangerous tropical storms (typhoons) to occur much more often than they did in the middle of the last century.

As we would expect, climate change also leads to more frequent heat waves.

HEAT WAVE
is a period of at least five days, during which the average daily temperature is at least 5°C higher than what is normal for these days of the year.

A recent study published in *Nature* magazine says that heat extremes that previously occurred only once every 1,000 days are now experienced every 200–250 days. However, the effects of warming will vary around the world. Weather events at the equator will become more extreme, meaning poorer tropical countries with already frail infrastructure will experience more than 50 times as many extremely hot days and 2.5 times as many rainy ones. But some already dry regions including parts of the Mediterranean, North Africa, Chile, the Middle East, and Australia will have higher risks of droughts and freshwater shortages.

Another study in the same issue of the magazine concludes that we are now entering an era with heat extremes that simply would not have occurred without climate change. Using an event-attribution analysis that links actual events with climate change, it shows that the prolonged heat-wave conditions in both Siberia and Australia in 2020 would have been virtually impossible without climate change. The Siberian heat wave resulted in massive forest fires (releasing an estimated 56 million tonnes of CO_2 into the atmosphere) and a collapse of infrastructure from the melting of permafrost, leading to the declaration of a state of emergency. A state of emergency was also declared for the Australian bushfires, associated with exceptional summer heat from late 2019 to February 2020, also known as the Black Summer.

Scientists who analysed the observed record highs in the southern hemisphere's winter and spring in 2023 concluded that those temperatures were made 100 times more likely by climate change.

But it is important to remember that unusual weather is not equivalent to climate change. For example, a very cold winter does not necessarily mean that the climate has become cooler. Data must be collected over a long period (about ten years or more) before we can attribute changes to climate change.

Weather anomalies can cause huge damage to the world economy and lead to the loss of many human lives.

Examples of extreme weather phenomena in recent years

On 13 September 2023, torrential rains from Storm Daniel swept across several areas in eastern Libya. The port city of Derna was the hardest hit, with entire neighbourhoods swept away after two aging structures collapsed, creating a catastrophic situation. The International Organization for Migration office in Libya stated that at least 30,000 people were displaced, and the death toll quickly rose to at least 11,300.

A key reason for the high loss of lives was the lack of dam monitoring or evacuation orders despite Storm Daniel's known path. The lack of state capacity to co-ordinate disaster relief efforts worsened the human impact.

The disaster in Libya comes after a string of deadly floods around the world in September 2023, from China to Brazil and Greece.

Tropical cyclones hitting underdeveloped and underprepared countries like Myanmar, Bangladesh, India, the Philippines, and Honduras have also seen very high death tolls in the past. Nations without the resources and political stability to adequately prepare for natural disasters bear damages with huge consequences for people and the economy.

Figure 2.1.3 **The city of Derna, Libya on Wednesday, 13 September 2023. Floods from torrential rains killed thousands of people and washed entire neighbourhoods into the sea**

Extreme weather events in Africa in 2023

While Libya's floods in 2023 made global headlines because of the scale of the death toll, many other deadly extreme events in Africa failed to make international news. An analysis of all disaster data, humanitarian reports and local news stories by the research think tank, Carbon Brief, helped to create a more complete picture of the scale of extreme weather impacts in Africa in 2023 to date.

It shows that at least 15,700 people have been killed in extreme weather disasters in Africa in 2023 and 34 million have been affected by extremes:

- More than 3,000 people were killed in flash floods in the Democratic Republic of the Congo and Rwanda in May. Scientists were unable to assess the role of climate change in the disaster because of a lack of functioning weather stations recording data in the region.
- At least 860 people were killed in floods and mudslides in February during Tropical Cyclone Freddy, the longest lasting cyclone on record affecting Madagascar, Mozambique, Mauritius, Malawi, Réunion and Zimbabwe.
- More than 29 million people continue to face unrelenting drought conditions across Ethiopia, Somalia, Kenya, Djibouti, Mauritania, and Niger.
- Countries in southern Africa have sweltered in a months-long winter heatwave, leaving many facing summer-like conditions for a continuous year.

Examining all recent extreme events and based on recent data, the National Aeronautics and Space Administration of the United States (NASA) confirmed that as Earth's climate changes, it is bringing about extreme weather across the planet. Record-breaking heat waves on land and in the ocean, drenching rains, severe floods, years-long droughts, extreme wildfires, and widespread flooding during hurricanes are all becoming more frequent and more intense. NASA's satellite missions, including the Earth System Observatory, provide vital data for monitoring and responding to extreme weather events, with explanations for each of them (Fig. 2.1.4).

Figure 2.1.4

The rotating graphic summarizes how climate change influences extreme weather across the planet, resulting in heat extremes, wildfires, droughts, tropical cyclones, heavy precipitation, floods, high-tide flooding, and marine heatwaves

Heat extremes: Since 1950, the frequency and intensity of heat extremes have increased primarily due to human emission of greenhouse gases. This includes high temperatures and dangerous heat waves. These events will become even more severe and common as the planet warms.

Wildfires: Hot, dry conditions raise the risk of wildfires. Acting as fuel, dry vegetation allows fires to keep burning once they start. As temperatures continue to raise globally, wildfires could become more frequent and intense in some regions, threatening lives and property.

Droughts: As the planet warms, some dry areas are getting drier. Warmer temperatures lead to greater evaporation of water from the surface, turning it into water vapour in the air. Since warmer air can hold more water vapour, this creates a cycle that leads to greater warming and even more evaporation. With less surface moisture, droughts of increasing frequency and severity occur.

Tropical cyclones: With a warmer ocean and more moisture in the air, tropical cyclones can produce more intense and sustained rainfall. Hurricanes, typhoons, and tropical cyclones are also raising coastal flood risk because rising seas lead to higher storm surges. Plus, the storms that form have a greater chance of rapidly intensifying.

Heavy precipitation: As the Earth's temperature rises, the warmer atmosphere can hold more water vapor – providing more water for intense rainfall, snowfall, and other precipitation from storms. Heavy precipitation is already occurring more often and will become more frequent and intense with increasing global temperatures.

Floods: Increases in water vapour in the atmosphere mean some wet areas will get wetter. Extreme precipitation can exceed the capacity of natural and human-made drainage systems, leading to damaging floods. Rising sea levels will also worsen flooding near the coast.

High-tide flooding: As global temperatures increase, ocean warming, and the melting of land ice are causing sea levels to rise. This means high tides will become higher, leading to a greater risk of flooding even when it's sunny. This is already occurring in some coastal cities like Miami and Bangkok.

Marine heat waves: Global warming can lead to extreme heat waves within the ocean. Corals and other marine life are not necessarily adapted to these higher temperatures and may die during multiple-day heat waves. Just like on land, marine heat waves are predicted to get more frequent and intense as the Earth warms.

Combined impacts: Many of these extreme weather events happen in combination with others. For some locations, heat waves and droughts are occurring together more often, a trend likely to continue as the planet warms. The same goes for flooding events, as heavy rainfall from storms and rising seas will increase potential damage along coastlines.

Can we predict extreme weather in advance?

Unfortunately, in most cases it is impossible to predict extreme weather phenomena. The maximum weather forecast range is up to 14 days, as the atmosphere changes completely every two weeks and air flows cannot be tracked for a longer period. For example, the most that can be said in advance is that 'the winter will be 1°C cooler than usual on average'.

Short-term forecasts are more accurate. Weather forecasts for tomorrow, made by European meteorological services, are correct in 96% of cases, predictions for the day after tomorrow are right in 93% of cases, and 90% of three-day forecasts come true. At present long-term warning of severe weather events can be made only in general terms. For example, it can be predicted that the extremely high temperatures, which are now seen in northern Eurasia every 20 years, will occur three times more frequently (once every seven years) by the mid-21st century, and probably every three to five years by the end of the century, making them almost a common phenomenon.

Should we put faith in weather lore?

Weather lore is folklore related to the prediction of the weather. Despite its popularity, it is of no help when it comes to weather forecasting. Even in the days of our grandfathers and grandmothers, traditional ways of predicting the weather often failed to work, and nowadays weather lore has completely lost its linkage to specific places where it might have been applicable. For example, the English have a saying, "Ash leaf before the oak, then we will have a summer soak; oak leaf before the ash, the summer comes without a splash." This used to be true in certain parts of Britain. But people began to move around the country and abroad, taking the saying with them. The result has been confusion, and weather lore has lost any validity it might have had.

What are we to do? How can we deal with extreme weather events? Can we adapt to them?

The United Nations has recommended early warning systems as key elements of climate change adaptation and climate risk management, particularly for extreme weather events and sea level rise. Such systems can help communities living in coastal areas, along flood zones and reliant on agriculture, to deal with flooding and cyclones and thus reduce their vulnerability to extreme events. United Nations Secretary-General António Guterres has called for every person on the planet to be protected by early warning systems by 2027. He launched the Early Warnings for All Initiative (EW4All) in November 2022 at the Climate Change Conference (COP27) in Sharm El-Sheikh, Egypt. The United Nations also launched a partnership, Climate Risk and Early Warning Systems, to help high-risk countries with neglected warning systems in developing them. Similarly, WHO recommends early warning systems to prevent increases in heatwave-related morbidity and disease outbreaks.

Hurricane Irma in Antigua and Barbuda in 2017

There are several good practices in reducing the damage and devastating impacts of storms and hurricanes. In Barbuda, Hurricane Irma wreaked havoc in 2017, resulting in huge losses to property and the evacuation of all 2,000 inhabitants of the Caribbean Island to neighbouring Antigua. With financial assistance of of US$10 million from the global Adaptation Fund, Antigua and Barbuda have been implementing a climate change adaptation project since 2017. The project is designed to help the most vulnerable communities in the coastal McKinnon watershed to build resilience against flooding, hurricanes, and higher temperatures by adopting an integrated approach. Measures include restoring natural drainage canals and climate-proofing vulnerable homes and storm shelters to reduce flooding and disaster risks:

- Restoring natural drainage canals: by cleaning, widening and deepening drainage canals, retention ponds and culverts to natural sizes, this measure aims to build capacity to handle extreme rainfall and storms.
- Climate-proofing vulnerable homes: by providing access to an innovative, low-interest revolving loan programme, this measure helps vulnerable households to climate-proof their homes.
- Storm shelters to reduce flooding and disaster risks: by supporting community groups in depressed areas with grants, this measure sought to develop climate-resilient buildings to serve as storm shelters. The project also enhanced collaboration with other funds such as the Global Environment Facility's Special Climate Change Fund by undertaking a hydrological study with their support and providing potential to scale it up.

Source: www.adaptation-fund.org.

In addition, you don't need to be a scientist or a climatologist or even to work for the emergency services to answer the question of how to deal with extreme weather events. The answer is simple: you must start with yourself. You need to be observant, and you need to care. To be observant is a straightforward matter: keep up with the latest science news; don't ignore calls to consider climate change when you work on long-term projects (for example, the construction of a new railway in a permafrost area should consider the increased melting of permafrost). To be caring is a more complex task: we need to be more careful in our behaviour and change our habits – we need to learn how to save energy and how to behave in extreme weather situations. For example, it is useful to know how to provide first aid to somebody who has fainted from the heat.

How to keep safe in a hurricane, storm, whirlwind or tornado

When you hear a storm warning:

- close doors, windows, attic hatches and vents
- remove items that could be carried by the wind from windowsills, balconies and loggias
- turn off gas, water and electricity, extinguish fires in stoves and fireplaces
- prepare stocks of food and drinking water
- make sure you have all essential things and documents
- take shelter in a basement or a strongly built structure

If a hurricane, storm or tornado occurs without warning:

a) if you are at home:
- move away from the windows
- stay in your home and hide in a safe place (the basement or ground floor is best)

b) if you are outdoors:
- take shelter in an underpass, shop or the porch of a building
- find natural shelter (a ravine, pit, ditch, etc.), go as far down as possible and lie flat on the ground
- stay away from billboards, bus stops, trees, bridge supports, power lines;
- do not in any circumstances touch electrical wires that have been torn loose by the wind

Do not leave your shelter immediately after the extreme weather has passed, as more strong winds could blow unexpectedly.

QUESTIONS

1 Is it harder to predict the weather for urban and rural areas? Why?

2 Imagine that your family wants to celebrate New Year out of doors. But what you do will depend on the weather: you might need to stay indoors if the weather is too bad. What is the earliest date when you will be able to predict the weather on December, at least roughly?

3 Why does extreme weather represent a danger to people?

4 Is an earthquake an extreme weather event?

5 Did the extreme weather events that we see nowadays (strong winds, floods, heat waves, etc.) also occur in the past?

6 What kind of adaptation measures are recommended to address the climate impacts of extreme weather?

TASK

Find out from your geography teacher what the main features of climate are in your location.

What was last summer like: was it warmer or colder than usual?

2.2 How climate change affects **plants and animals**

What is biodiversity?

BIODIVERSITY
is all the various species of plants and animals, fungi and micro- organisms, as well as the many combinations of environments (landscapes) and the huge number of variants between the genes of similar organisms. In other words, biodiversity is the multiplicity of forms and manifestations of life on Earth.

Scientists distinguish **three main types of biodiversity**:

- genetic (between organisms of the same species);
- species (between all of the living beings on the planet);
- landscape or ecosystem (between all the combinations of environments where organisms live).

What is **genetic diversity**? Take an example: all the geese in a flock of wild geese may seem the same. In fact, they are all slightly different from one another. Remember how, in the remarkable story about Nils' journey with the geese, each bird behaved differently. Of course, that is just a story, but it is basically true. One goose is quicker than the others to notice a fox creeping up on the sleeping flock across the ice; another remembers where to find a glade with lush grass beside a lake; and a third is better than the others at finding its way by the stars. So, the whole flock benefits from the special skills of the individuals in it. And this doesn't apply only to wild geese. Every kind of animal or plant needs to solve different problems to survive, and they do it better if they each have different special abilities than if they are all the same, like robots built on the same conveyor belt.

Genetic diversity brings new species into existence. Biologists believe that differences in behaviour and appearance – between two bears, for example – can increase over generations. And after many years the great-great-great-grandchildren of these bears settle in different regions, begin to hunt for food in different ways and prepare for hibernation differently (or even give up hibernation). That is how two different species came into existence – in this case, the Brown Bear and the Asian Black Bear.

Brown Bear

Asian Black Bear

The **difference between animals of different species and larger taxonomic groups**, such as phylum or class, is clear: you don't have to be a scientist to tell a dandelion from a plantain, a dragonfly from an ant, or a crow from a fox. But why are these and millions of other species of living beings so different?

African savanna and its inhabitants

Each species of organism on the planet has its own special role. In the African savanna, the top part of the grass is eaten by zebras, the parts further down by antelopes and wildebeest, while gazelles gnaw grass near the ground, and warthogs dig out the roots and tubers. So, plant food is completely used, and the different animals are not in competition. This means that most animals living in a particular region are well-fed and healthy, and the whole ecosystem will remain stable for a long time – all thanks to species diversity.

Ecosystem diversity is easy for any attentive traveller to see if one can distinguish an alder forest from a birch wood or a coral reef from mangroves. The countless variety of ecosystems in nature is like colourful scenery, against which the endless cycle of life unfolds – except that the scenery itself plays a very important part in the cycle. Species diversity creates living conditions for huge numbers of organisms, providing them with sources of food and water, shelter, and migration routes. For example, some plants living in moist ravines can survive a severe forest fire. If excessive numbers of a certain type of insect threaten potato crops, they will be stopped by a zone where the soil freezes to a considerable depth in winter. The greater the diversity of natural conditions, the higher the chances that various species will survive, and that the ecosystem will be preserved.

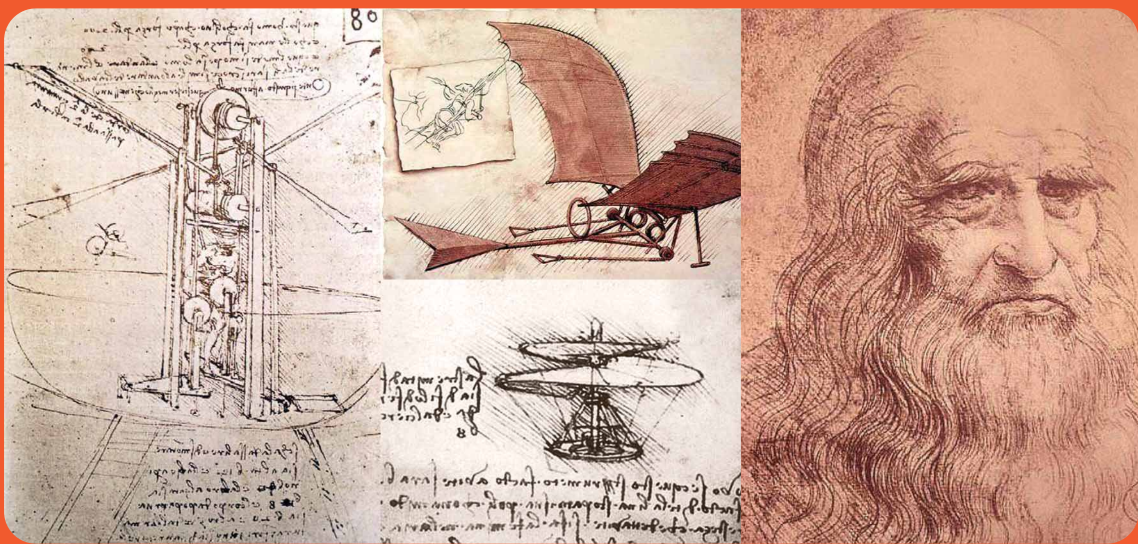
Species are unevenly distributed across the surface of our planet. The diversity of species in nature is at its greatest around the equator and decreases towards the poles. The richest species diversity is found in the ecosystem of tropical rain forests, which cover about 7% of the planet's surface but contain more than 90% of all species that are currently known.

Why is biodiversity so important?

Remember that until very recently (in historical terms) everything that people ate, and used to build their homes, as medicine, to make clothes, and for transport, was taken from nature. Yes, but not anymore, you might say. But you would be wrong. For example, modern scientists still spend much time searching in rainforests for natural raw ingredients for new medicines. Wild plant species are needed to create new crop varieties. And engineers have 'borrowed' many of their most original technical inventions from the kingdom of animals, plants, fungi, and microorganisms.

But that is not the most important role of biodiversity. What is most important is that biodiversity creates a habitat for all living beings, including human beings. What exactly does that mean? For many millions of years everything that grows, runs, swims, crawls, and flies on our planet, has adapted to the composition of the Earth's atmosphere. Changes to this 'cocktail' of gas might only be very slight. But even a slight reduction of the oxygen content in the air we breathe would make us and many other animals feel unwell. If oxygen levels fell even further, we would feel much worse. And what maintains the levels of oxygen in the atmosphere? Green plants!

The **science of bionics** offers solutions to engineering problems by using knowledge of the structure and functioning of living organisms. For example, the design of a new lining for the hulls of ships was based on studies of the structure of dolphin skin, and it has increased the speed at which ships can travel by 15-20%. The great artist and scientist, Leonardo da Vinci, was one of the founders of bionics: he tried to build an 'ornithopter', a flying machine with wings that flapped like those of a bird.



All plants and animals, micro-organisms and fungi form a highly intricate and finely adjusted system. Imagine that you and your friends spent two whole years on a spaceship flying to Mars and back. Think of all the different parts, devices, and other equipment that the spaceship would contain. Can you think of our planet being like that spaceship? Each of its 'parts' was created by millions of years of evolution, with the action of each part tuned to work in harmony with thousands of others. What would happen if an error by one of the crew or a meteorite damaged several devices on the spaceship? You could replace them with other similar devices, at least for a while. But what if you then suffered some other space accident?

Biological diversity in our planet is quite similar. Every organism has an important job. One processes energy from the sun, another uses that processed energy to chase prey or escape from predators, a third breaks down dead wood or the remnants of dead animals, and so on. Every one of them, from the vast baobab tree to the smallest lichen, from the mightiest whale to the lightest jellyfish, are all-important components of life on planet Earth. And there are organisms that we have yet to discover.

There may not be many of them, but they are also necessary. You might say: "There have been times in the history of life on the planet when whole groups of organisms became extinct. So, the loss of one species is no disaster, or even of a dozen or a hundred..." But stop! You are wrong! We don't know how many losses our 'spaceship' can tolerate. Perhaps we have already overstepped the mark. In the short history of mankind, nature has irretrievably lost not a hundred or a thousand species, but many more.

Another important point is that biological diversity can be viewed as a measuring device that shows the sustainability and state of health of the natural world. If there are plenty of different species of living organisms, all playing their proper role, then the tropical rainforest, ocean reef or forest wetlands can continue to exist far into the future.

Ever since the beginning of history, one of the harshest punishments has been to lock a person for a long period of time in a small cell with grey walls where they cannot see the sky or communicate with fellow human beings.

If the world contains fewer plants with beautiful and fragrant flowers (or even inconspicuous and odourless flowers), fewer weasels and twirling swifts (or clumsy armadillos and slow-moving tortoises), then our shared planetary home will become more and more like a dull, grey prison cell.

What are the threats to biodiversity?

Human activity poses the biggest threat to the undisturbed existence of wild nature in all its biodiversity. We cut down forests, plough up the steppe, burn savannas, drain swamps, hunt for game, catch fish, and pollute our rivers. Of course, we do not intend to destroy the natural world. We want to feed our growing population, obtain wood to make things, produce energy, breed livestock, make room for our cities, roads, military sites, and landfills, and much more. Biodiversity is highly vulnerable to changes in natural conditions – from changes in temperature, forest fires, and melting of permafrost to drying out of wetlands and fluctuations in the level of the ocean. You already know why these changes are happening.

One unusually hot summer is not a disaster. Over thousands of years of evolution, plant and animal life has adapted to short-term fluctuations in the climate and gradual changes in nature. But what does pose a threat to biodiversity is rapid and irreversible changes in the environment, particularly changes in the climate. Let's try to figure out why.

Mass extinctions and climate change

Throughout the entire period of life on earth that is known to science (three billion years, no less), there were several dozen periods of abrupt climate change that led to a marked reduction in biodiversity. Five of these stand out and are commonly referred to as the 'great extinctions.' One of the most dramatic occurred about 250 million years ago. At that time the Earth was not yet populated by the plants and animals familiar to us now, but the diversity of life was already substantial. And then, quite suddenly in geological terms, in the space of a few million years, nearly all species of animals and plants disappeared (there were far fewer plant than animal species at the time, since life in the oceans and seas, consisting mainly of animals, was much richer than on land).

The disappearance of certain species and the appearance of new ones is a constant process in the geological history of the Earth's biosphere: no species can exist forever. Extinction has been compensated by the emergence of new species, and the total number of species has grown. The extinction of species is a natural evolutionary process that occurs without human intervention.

What mysterious causes led to the almost complete extinction of some species and the emergence of others? Scientists have strong reasons to suppose that the main causes were major changes on the planet surface, namely the drift of continents over the Earth's crust (we learned about this in previous sections). Continental drift transformed the layout of the natural world as it then existed, including the position of mountain ranges and the system of ocean currents, and, of course, radically changed the Earth's climate. After ancient eras when the world was cooling down, there came a time of climate warming. The climate became drier and seasonal fluctuations in temperature increased. The levels of oxygen in the surface atmosphere also changed. All this led, as we have seen, to the large-scale replacement of certain species by new species of living beings.

The extinction of species was repeated, but never again on the scale of this first event. About 60 million years ago there was another abrupt alteration of conditions on the planet, which led to the extinction of the last dinosaurs. This was also accompanied by climate change, which sped up the process of replacement of some animals and plants by other new species. Other groups of living beings, such as ammonites (sea molluscs similar in shape to rams' horns) and belemnites (whose fossils resemble arrowheads), followed the dinosaurs out of existence. Almost half of all sea creatures disappeared at that time, and how many disappeared on land is not precisely known, because the remains of land organisms are much less well preserved.

Ammonites

Belemnites

The cooling of the climate was accompanied by the formation of ice caps at the earth's poles. The huge tracts of ice that now exist in Greenland and Antarctica can be seen in photographs of Earth from space. How much water is needed to form such ice caps? A great deal. And where does it come from? Only from the ocean. When ice caps form, sea levels drop and living conditions for all organisms that live along coasts, in water and on land, change drastically.

So, among its other effects, climate change affects biodiversity and, in the initial stages, makes it worse. Afterwards life on the earth gradually recovers, but it never reappears in its previous form. Millions of years are required for recovery, and species that have become extinct will never return. Do we want to face extinction as a species?

Which animals react most quickly to climate change?

Of course, everything that we have discussed up to now happened in the long distant past, a past so distant that we cannot even imagine it. But how is climate change in our time impacting wildlife in all its diversity?

The impact of human activity and abrupt climate change has led to rates of species extinction across the planet that are many times greater than the rates that occur in nature.

Small animals with short life cycles are particularly dependent on environmental conditions and therefore respond faster to climate change. Of course, large organisms also react but, in their case, the effect take much longer to see. For our purposes as researchers, we want to know about events taking place today or will take place soon that we will live to see.

A modest but sustained rise of average temperatures by 1.5°–2°C in the mountains of Slovakia has led to unexpected consequences. Beautiful, warmth-loving butterflies of the swallowtail family – the Podalirius and Machaon – have spread beyond the forest-steppe zone, in which they lived, and begun to appear in cooler and damper meadowland. They have also begun to reproduce three times a year instead of twice, as before.

Other butterflies, of the Araschnia genus, previously had a different colour depending on the season: brown in spring, black in summer and brown again in autumn. But they have now assumed black colouring at all times of the year.

Also in the Slovak mountains, biologists have established two opposite tendencies in the life cycles of the spruce bark beetle and the winter moth caterpillar. The beetles have expanded their habitat area as temperatures have increased, while the voracious caterpillar now feeds less on its favourite trees. In both cases, there is a direct correlation between temperature changes and insect behaviour.

Machaon butterfly

Spruce bark beetle

The yellow-striped pygmy eleuth is a small frog that inhabits tropical forests, where fluctuations in temperature and humidity during the day and through the year are small but do occur. Scientists became interested in the peculiarities of the relationship between the frog and a parasitic mould that grows on its body. It was found that the parasite is much less vulnerable to a change in environmental conditions than its host. So, climate change makes the parasite more dangerous to the frog, jeopardizing the entire population of the host species.

Yellow-striped pygmy eleuth

In the cold waters of the Southern Ocean, even the slightest increase in temperature leads to an increase in acidity and reduction of oxygen content. This has led to mass migration by bivalvular molluscs of the species Laternula elliptica away from the danger zone. However, older molluscs (aged more than three years) lack the muscle strength to migrate and are perishing in large numbers. You may ask: can't these creatures settle in new regions and restore population numbers? But it is not so easy: the species is only able to reproduce after the third year of life, when it loses mobility.

Laternula elliptica

Coral reef

Corals have also been among the first to be affected by climate change. Corals are highly sensitive organisms. Water that is too warm or too cold, lack of light and excess impurities all act to slow down or stop the growth of corals. Coral polyps cannot move about and are very poorly adapted to environmental changes. They must live and die where they are born. The micro-algae that absorb the energy of sunlight for coral polyps are very dependent on water temperature. At many places on Australia's Great Barrier Reef, scientists are seeing the death of algae and bleaching of the coral, which occurs when the reef dies. This is because repeated marine heat waves over the last several years have turned much of the Great Barrier Reef a ghostly white colour. Smoke from severe forest and peat fires in Indonesia often leads to atmospheric emissions of iron compounds, which cause the rapid flowering of algae that produce substances that are toxic for corals.

Yet, there are some recent successful innovations in saving corals. The Australian Institute of Marine Science is propagating large numbers of healthy corals in an aquaculture facility to gain a deeper understanding of coral reproductive biology and ecology. The institute is collecting coral fragments from the reef, which are spawned and fertilized, and the larvae then reared in nurseries and settled onto specially designed surfaces. Settled corals, or fragments made from the adults, are placed on devices on the reef. Divers then revisit the sites to identify and understand the environmental conditions in which corals survive and grow best. This knowledge will help design and upscale coral aquaculture systems to enhance end-to-end survival of corals on degraded reefs, from spawning to settlement and adulthood.

Salps

Warming in polar regions is reducing the area of seasonal sea ice, the underside of which is a breeding ground for microscopic ocean plants, called phytoplankton. Phytoplankton are at the beginning of a food chain, which includes krill, fish, penguins and other seabirds, seals, and several sub- species of whales. If there is not enough ice, the phytoplankton cannot grow and breed in sufficient amounts. Krill cannot live in water that lacks sustenance, and their place is taken by translucent, jelly-like salps, which are ancient creatures. This causes an interruption of the food chain as hardly any animals eat salps, except for a few species of fish and sea turtles. So, whales cannot build up sufficient reserves of fat in the winter months, and other creatures also forsake waters that lack the food they need. Once again, we see the complex inter-relationships that exist in nature and are reflected in biodiversity.

The shrinking northern polar ice cap is the most visible sign of climate warming. Polar bears need ice for their migration and to hunt for seals, and the ice is also vitally necessary for the seals themselves, as without it they have nowhere to rear their young. If ice fields start to shrink more than is usual each summer, the seal population also shrinks and hungry polar bears eat the whole carcasses of the seals they catch, instead of devouring only the seal's layer of fat. Previously the remains of a polar bear's meal provided a feast for other inhabitants of the Arctic – the Arctic fox and numerous birds. But now there is nothing left over for them!

Polar bears

As the climate becomes warmer, the forest in the northern fringe of Eurasia is slowly but surely advancing into the tundra at a rate of tens of kilometres each century. This changes the habitat and food sources of numerous types of birds. Warm winters in the Arctic are also disastrous for both wild and domesticated reindeer, as thaws and rainfall in the winter cover the snow with a crust of ice, making it harder for the reindeer to find lichens, which are their staple diet during the winter months.

Reindeer

The lemming, the most numerous inhabitants of the tundra, is also suffering from the warmer climate. The holes they live in are now flooded with water too early in the year, reducing the lemming population and forcing birds of prey and foxes to go hungry.

Lemmings

In the Southern Hemisphere, on the Antarctic coast, which has the appearance of an ice desert with rocky outcrops and very sparse vegetation, researchers are suddenly finding abundant thickets of Antarctic hair grass, a small plant that previously grew only in small clumps between stones, sheltering from the icy winds of the southern continent.

Tolai hare

In the Daurian steppe of eastern Russia, between Lake Baikal and the Greater Khingan Mountains of Mongolia, scientists have noted that the climate is growing more arid because of global warming. Lakes and small rivers are disappearing, forest belts are drying out and the vegetation on the steppe is burnt by the sun earlier in the year. The animal inhabitants of the steppe are doing what they can to adapt to the change. Larvae and fish spawn bury themselves deep in silt at the bottom of water courses. Birds migrate to other places, changing their flight paths and nesting sites. There is insufficient food for all the local water birds, such as the cormorant, grey heron, and herring gull. The swan goose no longer nests in the region. Wolves, foxes, badgers and even cranes are moving away in search of more water. Birds of prey, which need plenty of water to digest their diet of meat, are also migrating to more suitable regions. The Tolai hare finds itself short of grass in the summertime, not only to feed on but also to hide from predators. The Tabargan marmot and Daurian ground squirrel, both indigenous to the area, are well-adapted to drought, but are finding life in the new conditions difficult, as they cannot move quickly enough to escape grass fires, an increasingly frequent occurrence in the summertime. Burnt grass also means a lack of winter forage for hoofed beasts, forcing large herds of antelope and gazelle to migrate from Mongolia to Russia.

Manul

The few remaining watering places in the Daurian steppe are now overcrowded with animals in search of water, which increases the risk of disease. As summers become drier, winters have experienced more snowfall, because of which the manul (a species of wild cat) cannot find food. The Daurian hedgehog is almost alone in benefiting from the change of climate: it needs more than five months of warmth for a successful life cycle, so it is expanding its presence in the new conditions.

National parks: learning to preserve nature

What is a national park? It is a protected area that can be visited by tourists, where human activity is limited by definite rules. National parks are usually created in places where there are many different landscapes (both typical and unique), rare or endangered animals and plants, and unique geological or water phenomena. Adults and children visit them to learn about global environmental issues. National parks can be used to create nurseries to breed rare species of plants and animals.

Does climate change affect national parks? Unfortunately, global climate change leads to fires, droughts, increases in temperature and many other phenomena that cannot be kept at bay simply by declaring an area to be a national park.

In the Everglades Park in Florida (USA), the conditions for freshwater flora and fauna vary depending on the influx of salty seawater from the nearby Florida Bay, a process being influenced by climate change. Scientists and staff of protected areas understand that such processes threaten the very existence of national parks, and the US Environmental Protection Agency together with the National Park Service have set up Climate Friendly Parks. The programme acquaints park staff and visitors with the causes and consequences of climate change and explains what they can do to help solve global problems associated with climate change.

Lahemaa National Park (Estonia)

Jasper National Park (Canada)

Kruger National Park (South Africa)

The world-famous **Yellowstone Park** was established in 1872. It is the oldest national park in the USA.

The **Great Barrier Reef** is vital to the existence of many living organisms and is being seriously affected by climate change. It is protected as part of the Marine National Park in Australia. One of the seven natural wonders of the world, it is also listed as a World Heritage Site by UNESCO. It is the only living structure on the planet that is visible from space.

The longest pedestrian route through a protected area is also in the USA, in the **Great Smokey Mountains** National Park.

The **Namib-Naukluft National Park** in Namibia (Western Africa) is famous for its remarkable orange dunes that are the tallest in the world, in places rising more than 300 metres above the desert floor. The park has some of the most unusual wildlife and nature reserves in the world and covers an area of over 49,000 km^2 – more than the territory of Switzerland.

Yugyd Va National Park (Russia)

Wildlife reserves: nature without humanity

Wildlife (biosphere) reserves are places where scientists can monitor and record changes in the natural world. In a wildlife reserve it is forbidden even to pick berries or mushrooms or catch fish. Such places are ideal for restoring populations of endangered species, which can then be released into suitable areas outside the reserve.

Biosphere reserves are often created in places where nature is not subject to any substantial human influence. They are used to safeguard typical local ecosystems as well as rare species and communities of animals and plants. For example, the ecosystem to be protected in taiga regions would be that of the taiga, while in a tropical region it would be the tropical rainforest. The conservation of the natural environment in such areas has global importance.

Biosphere reserves exist on all the world's continents. You have probably seen films about such areas in Africa. It is thanks to such biosphere reserves that the diverse natural world of the African continent is being kept alive for us today.

Biosphere reserve Belavezskaja Pushcha / Bialowieza Forest (Belarus, Poland)

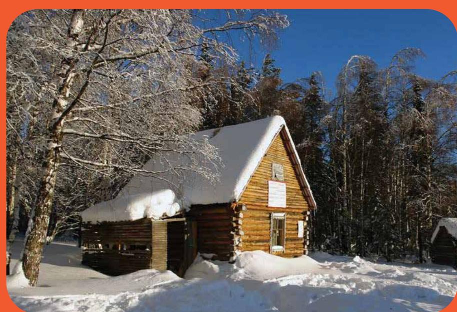
Everglades National Park (USA)

WILDLIFE (BIOSPHERE) RESERVE
is a protected territory where no human activity is permitted, apart from scientific activity.

All biosphere reserves participate in the Man and the Biosphere Programme, run by UNESCO, which supports long-term studies of the environment. Studies are now being carried out in many reserves of the impact of climate change on plant and animal life. Scientists working at the Caucasian State Biosphere Reserve in southern Russia have found that the forest cover on the slopes of mountains is gradually moving higher as the climate becomes warmer.

The **Zion National Park** in Utah in the USA is a fine example of how to achieve environmental safety. About 20 buses, using low-emission gas fuel, carry visitors around the park, replacing about 5,000 cars that visitors would otherwise bring with them. The result has been a significant reduction in greenhouse gas emissions. A 'Green Centre' built at the park to welcome tourists obtains nearly a third of its energy needs from the sun, with 80% of its lighting needs provided by natural light. In the summer the air conditioning system uses special energy-efficient evaporators. In the winter a passive heating system, which uses a wall of heat-absorbing materials (stone, brick) facing the sun, maximizes heat retention.

The **Taganay National Park** in Russia has installed the first eco-friendly energy supply system to be used at a protected natural area in the country. One of the shelters in the park now obtains its electricity from wind energy (wind turbines) and the sun (solar panels). The system automatically determines which of the two sources of energy, solar or wind, should be used at any moment. Previously this and other shelters and facilities at the park were dependent on gasoline- powered generators, an energy source that is both expensive and harmful for the environment. A new lighting system, powered by solar and wind energy, has been installed in Adler at the **Yuzhniye Kultury** section of the Caucasian State Natural Biosphere Reserve in southern Russia.



Wildlife sanctuaries and areas of outstanding natural importance

The point of wildlife sanctuaries is to protect not the whole of the local natural environment, but only individual parts of it: for example, only plants or only animals, or perhaps some geological features (rocks or caves). So, their restrictions on human activity only refer to activity that threatens the protected parts of the environment.

Areas of outstanding natural importance are unique or typical natural areas and landmarks, which have special scientific, cultural, educational, or health-related value. They may be lakes, trees, geological sites, or ancient parks. They are protected by prohibitions on certain kinds of human activity that could damage their integrity.

How do protected areas help to address the problems of climate change

What is the contribution of a national park (and any other protected area) in addressing climate change? The most significant contribution is the reduction of emissions of carbon dioxide into the atmosphere. For example, some parks encourage tourists to use public buses powered by alternative fuel instead of polluting private cars. Park employees themselves also use forms of transport that have minimal impact on the environment. Parks may use energy from the wind, sun, or hot springs in the premises where they receive visitors. Maximum use is made of natural lighting and LEDs, and solar panels provide power for offices. Tourists are offered souvenirs made from recycled materials, the park cafeteria serves dishes made from local products (avoiding 'food miles' and the accompanying transport pollution), made in an environmentally safe manner, and park premises are equipped with water-saving toilets. Visitors receive information on how to behave in a way that is most environmentally efficient and least environmentally damaging.

Ecotourism: harmony between man and nature

Do you enjoy walking and other outdoor activities? If yes, then you and your friends will enjoy travelling and discovering new places. Maybe you will even become ecotourists.

What is the difference between tourists and ecotourists? What sets them apart is their attitude towards the environment. Ecotourism is a recent concept that arose when people began to understand how important the natural world is to us. There are different ways of relaxing outdoors. You can drive into the forest or to the edge of a lake by car, switch on music at full volume, light a fire in the nicest place you can find, have a picnic, and leave a pile of garbage behind you. But there are other tourists who are willing to climb to the top of a mountain just to see a wild animal, find a rare plant, listen to the birds singing, or enjoy the sunset and the silence. Their goal is to see and hear the natural world, which modern people so rarely witness. They don't leave garbage – on the contrary, they often clear up other people's garbage, and make sure to obey all the rules in place to protect the environment. Happily, the numbers of ecotourists are growing year by year!

Ecotourism gives people the opportunity to see the environment in its untouched, natural state, understand how diverse it is, how vulnerable to human activity, and to ponder the question: ‘What can I do for my planet?’ Ecotourists study the laws of nature and do things that help to maintain and preserve it, they try to reduce their environmental impact to a minimum. What is more, ecotourism firms give a part of their revenue to support the protection and study of the environment.

Many outstanding natural environments are in remote places, in rural areas where people are relatively poor. They are also in areas such as the jungles of South America or mountain regions along the border between northern Thailand, Myanmar, and Laos, which are inhabited by indigenous peoples. Therefore, ecotourists often learn not only about the natural world, but also about human culture. And ecotourism provides work and an additional source of income for people who live in these regions.

So, ecotourism helps people to see the beauty and uniqueness of nature, understand how everything in the world around them is connected, learn how many species of animals and plants live on our planet, and realize the extent to which the state of the environment depends on the actions of each person, teenagers, and children as well as adults.

An eco-hotel in Costa Rica

What are the global Red List and Red Data Book and what are they for?

The Red List is a list of rare and endangered species of animals, plants, and fungi. The colour red reminds us of the risk to these species and the urgent need to protect and preserve them.

Lists of living organisms all over the planet, which need protection, are included in the International Red Book, the main copy of which is kept in the Swiss town of Morges. The book is published by the International Union for the Conservation of Nature (IUCN) and first appeared in 1963. This unusual book is designed like a desk calendar and is constantly changing: as time passes, the situation of species already in the book changes and the names of new species of plants, animals and fungi are added.

For each species it features, the Red Book provides information on the distribution, population numbers, habitat features, other details and measures required for its conservation. Its pages are in different colours. Pages describing extinct species are marked in black. These include, for example, the sea cow, the passenger pigeon, and the dodo. Pages marked in red deal with endangered and very rare species (the far-eastern leopard, the Amur tiger, the snow leopard and the European bison). Animals whose numbers are rapidly decreasing are listed on pages marked yellow (the polar bear, pink seagull, goitered gazelle). Animals and plants rarely found in the wild are recorded on white pages. Species that have not been sufficiently studied because they live in remote places are recorded in grey. The most encouraging are the green pages, which record species that people have succeeded in saving from extinction (e.g., the Eurasian beaver and the Eurasian elk).

Each country and region in the world also create their own lists of rare and protected species.

Before a particular species is included in the Red Book, scientists carry out intensive studies of the flora, fauna, and fungi in relevant areas, find out the causes which threaten the species, describe their habitats, and decide how they should be preserved. The Red Book not only contains rare and endemic species (species found only in a specific territory), but a whole range of flowering, edible and medicinal plants.

Animals and plants may need to be protected for two groups of reasons: direct and indirect. There are direct reasons for protection when people destroy animals and plants through hunting, gathering medicinal plants, fishing, or collecting aquatic organisms. Indirect reasons relate to change of habitat, including that which is caused by global climate change. Such indirect reasons may include difficult acclimatization to climate change, the introduction of new species of plants (when 'newcomers' displace native species, for any of various reasons) and the destruction of plants that are a source of food for animals.

What are the adaptation solutions based on ecosystems?

Available adaptation solutions can build resilience to climate risks and, in many cases, simultaneously deliver broader sustainable development benefits.

One of these solutions is ecosystem-based adaptation that can help communities adapt to impacts already devastating their lives and livelihoods, while also safeguarding biodiversity, improving health outcomes, bolstering food security, delivering economic benefits, and enhancing carbon sequestration. Many ecosystem-based adaptation measures — including the protection, restoration, and sustainable management of ecosystems, as well as more sustainable agricultural practices like integrating trees into farmlands and increasing crop diversity — can be implemented at relatively low costs today. The key to their success is to engage local communities and ensure that strategies are designed to account for how a rise in global temperature will impact ecosystems.

Figure 2.2.1 Ecosystem-based adaptation that can protect lives and livelihoods

QUESTIONS

1 Which of the Earth's ecosystems is the richest in terms of species diversity?

2 What is meant by 'direct' and 'indirect' causes of the extinction of living organisms? Give examples.

3 How would you and your friends begin a story in class about the importance of biodiversity? What arguments are the most persuasive for schoolchildren and which for adults?

4 Why are the Red Book and the Red List red? What plants, animals and fungi do you know that have been listed in the Red Book? Why are they disappearing? Can we help to preserve them?
What different colours are used on the pages of the Red Book?
Why does the Red Book become longer each time it is updated?

5 How does global warming affect reindeer?

6 Who can fairly be called an 'ecotourist'?

7 What kind of adaptation measures, mentioned in this chapter and others, can you recommend that address climate impacts on biodiversity and ecosystems?

8 What solutions form part of ecosystems-based adaptation?

TASK

Working together with the rest of your class, create your own Red List. Draw an animal, plant, or fungus in need of protection on a page of a certain colour and explain your choice.

2.3 How climate change affects **forests**

What is a forest?

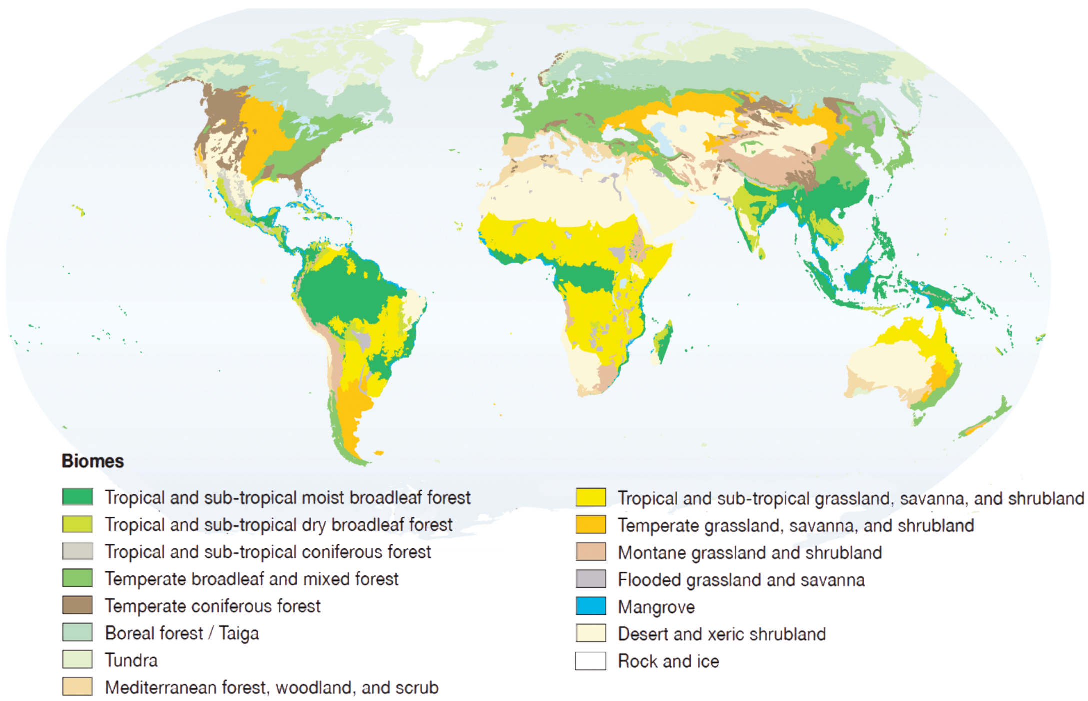
Although 'forest' is a commonly used word, it is not easy to clearly define what it is, as it largely depends on the national context. There are more than 800 different definitions for a forest around the world! But the most recognized approach to identify a forest, used also by the Food and Agriculture Organization, defines forest using indicators such as: 1) trees of minimum height of 5 m, 2) at least 10% for crown cover (proportion of the ground shaded by the crowns of trees) and 3) a minimum forest area size of 0.5 hectares. By this definition, there are just under four billion hectares of forests on Earth, covering about 30% of the total land area. About half of the world's forest areas are in three countries: Russia, Canada, and Brazil.

Types of forests

Forests are usually classified in terms of the predominant tree species – broadleaf, coniferous (needle-leaved), or mixed – and their leaf longevity (whether they are evergreen or deciduous). The main biomes of the world are presented in Fig. 2.3.1 and include the following forest types:

- **Boreal forests** (taiga) are generally evergreen and coniferous.
- **Temperate forests** include broadleaf deciduous forests, evergreen coniferous forests and a mix of both types. Warm temperate zones support broadleaf evergreen forests.
- **Mediterranean forests** are generally composed of evergreen broadleaf and sclerophyll trees. Sclerophyll means 'hard-leaved' in Greek, as such trees usually have small, dark leaves covered with a waxy outer layer to retain moisture in the dry summer months. Coniferous forests also occur in this zone.
- **Tropical and sub-tropical** forests include moist broadleaf forests, dry broadleaf forests, and coniferous forests.

Figure 2.3.1 **The main biomes of the world**



Why are forests dependent on the climate?

The life of the forest and its geographic distribution depend on climatic conditions, especially air temperature and the amount of precipitation. Only in some places on our planet is the climate suitable for forests to grow. For example, the location of the northern-most forest line depends on the average annual air temperature. Where it becomes too cold, boreal forest is replaced by tundra. However, air temperature, especially on the plains, changes only gradually. So, the border of the forest and tundra becomes a transition zone, where areas of both tundra and forest are found. This transition zone is called forest-tundra (Fig. 2.3.2).

The southern line of temperate forests, where forests give way to grassland (steppe) and semi-desert, is determined by rainfall. In hot conditions, plants and trees are constantly losing moisture from their leaves to keep cool. If rainfall in the summer is scant, there is not much moisture in the soil, and trees have difficulty drawing it upwards as high as their crown. Because the air is warm and precipitation is limited, low herbaceous plants are at an advantage and the landscape becomes steppe.

Relief, soil quality, water bodies and human activity are also important in determining forest cover. The share of forest diminishes in regions where much of the land has been put to work in the economy.

Figure 2.3.2 Forest-tundra

Forests of temperate and sub-arctic climate zones

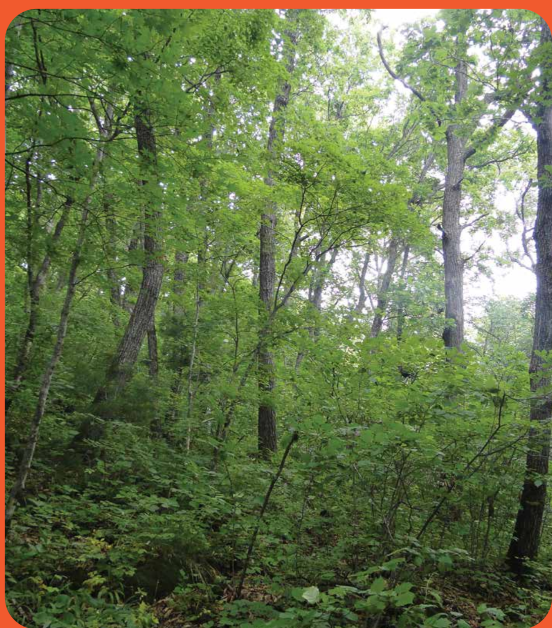
Boreal forests (taiga) are dominated by coniferous tree species: pine, spruce, larch, fir and cedar. It is interesting that such forests in Europe and Western Siberia consist mainly of pine and spruce, while in Central and Eastern Siberia they are mainly larch trees. This is due to the permafrost in the vast Siberian territories, which make these areas particularly well suited to larch.

Differences in temperature conditions (average summer temperatures, times of formation and melt of the snow cover) justify subdivision of the taiga zone into northern, middle, and southern taiga. Mature trees in the forests of the northern taiga do not grow high, reaching 10–20 m, while in the southern taiga they may be as high as 50 m (Fig. 2.3.3). The middle taiga is intermediate between the northern and southern, not only geographically, but also in terms of the average height of trees, which grow to 20-25 m.

The area to the south of the taiga is occupied by a zone of temperate deciduous forests (Fig. 2.3.4). It is dominated by various species of oak, hornbeam, and elm. Such trees are commonly known as deciduous hardwoods (because their wood is relatively hard). To the south of the deciduous forests in Eastern Europe and Central Asia, the grassland (also called 'steppe') begins, and the transition zone is called forest-steppe. However, there is no deciduous forest zone in western Siberia and the central regions of North America (Fig. 2.3.1), where taiga gives way immediately to grassland. This is due to the regions' continental climate: rainfall is low, so the ground is very dry and deciduous forests, which need a lot of moisture, cannot grow.

Figure 2.3.3 **Southern taiga**

Figure 2.3.4 **Deciduous forest**



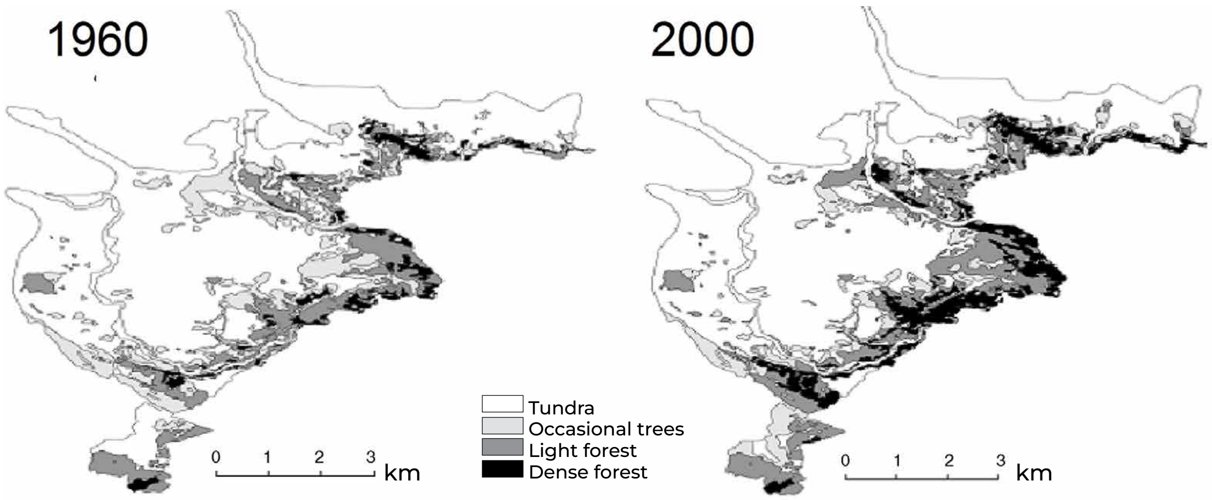
Does climate change taking place today have an impact on forests?

Are forests affected by the current warming of the climate? Yes, they are!

Climate change will have many widely varying effects on trees and the composition of tree species within forest ecosystems. As the climate continues to change, trees must either adapt to new conditions or migrate to more suitable locations.

Changes associated with global warming are particularly apparent on the northern boundary of boreal forests. In polar regions, trees and shrubs rise are moving higher up the mountain slopes, gradually usurping the place of mountain tundra (Fig. 2.3.5). The upper boundary of larch trees on mountain slopes of the Polar Urals (Russia) has moved upwards by 35–40 m in the last 80 to 90 years and by 50–80 m in some regions. Shrubs are now growing more than 50m higher up on slopes in the Khibiny Mountains on the Kola Peninsula (Russia), and an intensive growth of shrubs, particularly willows, has been observed in Scandinavian tundra zones.

Figure 2.3.5 Change of vegetation cover in the Polar Urals (Russia)



Heat is driving trees up mountains in South America

Trees and shrubs in mountainous regions of South America are fleeing unbearable heat on the plains by moving up the slopes of the mountains where the air is cooler, making it possible for them to survive. In the Andes, trees are moving up mountains by an average of 2.5–3.5 m each year. This is a considerable feat for plants, which cannot move except by reproducing. But climate change is happening so quickly in the Andes that trees need to climb more than six metres each year to remain in a comfortable temperature.

Of the 38 plant species being monitored by scientists, the Scheffleris species is migrating the fastest of all: it rises about 30 m higher each year. The fig tree is unlikely to survive in these regions by 2100 if global temperatures rise by 4°C as it is moving higher at a rate of only 1.5 m per year. Climate models suggest that more than 50% of tropical plant species could become extinct.

The southern boundary of the temperate forests is also changing. Oak forests are gradually disappearing in the forest-steppe and steppe zones due mainly to summer droughts. In the region around Lake Baikal, by contrast, pine forests are advancing into steppe ecosystems, due to increased precipitation. So, the southern forest line is shifting because of changes in moisture levels rather than an increase of temperature.

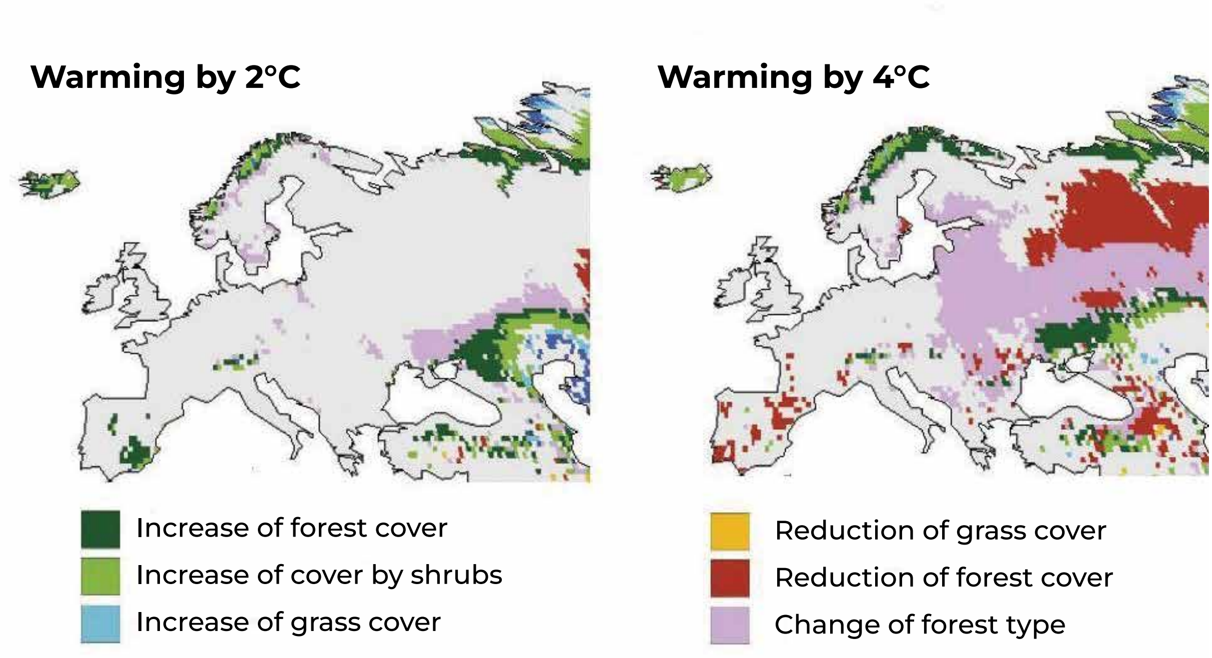
The areas of Russian forests that are occupied by tree species have changed in recent decades and scientists believe that this is largely due to climate warming. For example, oak forests have diminished in southern regions, but are gaining ground further north, on the border between deciduous forests and the northern taiga.

Spruce forest (Fig. 2.3.6) is in retreat in nearly all parts of Russia. The root system of spruce trees is close to the surface, which makes the tree highly sensitive to increase in the frequency and duration of droughts. At the same time, many regions of Russia are seeing an increase in birch forests. This phenomenon is well known to forestry specialists: it is because, after a fire or the felling of coniferous trees, birch and other small deciduous species initially appear in their place, and some time is needed before new coniferous trees appear and begin to displace birch, aspen and alder. However, in recent decades, this last stage has not been occurring: conifers seem unable to regain ground lost to birch forest.

Figure 2.3.6 Spruce forest

Most forecasts predict that forests in northern parts of Eurasia and North America will be more affected by global warming than forests elsewhere in the world, as their northern and southern boundaries are displaced. A rise in temperature of 2°C will cause an increase in the total area of forest cover in Europe of taiga to advance into the tundra zone. However, an increase in temperature of 4°C will cause the southern forest boundary to retreat northward and this effect will be greater than the northward advance into the tundra zone (Fig. 2.3.7).

Figure 2.3.7 **Forecast changes in forest cover in Europe by 2100, assuming global warming of 2°C and 4°C.**



Deforestation caused by climate change will affect almost all Eastern Europe and Western Siberia. This is a worrying forecast, showing how serious a phenomenon the disappearance of forests may be in a worst-case scenario for global warming.

Destruction of forests by fires, pests, and extreme weather

Another major threat to forests associated with climate change comes from large-scale fires and plagues of pests caused by hot weather in summer. Heat and other extreme weather events are often directly responsible for the destruction of forests.

Forest fires are usually started accidentally by people. But they can take hold only in certain conditions, namely, when the weather remains hot and dry for days or weeks. The forest floor of dead leaves, pine needles, small branches, mosses, lichens, and grasses growing under the forest canopy then becomes dry and catches light easily, and the fire can spread over large areas. This is called a ground fire.

When fire spreads in coniferous forests it often reaches the crowns of trees. Pine needles and small branches of fir and pine trees contain large amounts of resinous substances, so living trees can easily catch fire. A crown fire is the most dangerous and destructive and can lead to the complete loss of an area of forest (Fig. 2.3.8).

Fires cause great damage to the forest: many trees perish, their growth is stunted, the variety of trees in the forest becomes poorer, and the spread of harmful insects and pests is made easier. As the climate changes, the risk of forest fires increases because higher temperatures dry out woody materials more quickly. The warm season of the year, during which fires can occur, also becomes longer.


Figure 2.3.8

Forest fire

The unusually hot summers of 2010 and 2012 in the central part of European Russia weakened conifers that are accustomed to very different conditions. Such weakened trees are easy prey for many species of insects that live under the bark. In years when temperature and humidity levels are normal the population numbers of such insects are controlled by other species (insect and bird predators). But if the population of bark beetles becomes too large, large tracts of forest may perish! The dried-up trees first lose their needles, and then their bark. Various fungi that attack wood go to work on the roots, which are eventually unable to support the trees. Strong winds can then blow the trees down, one after another (Fig. 2.3.9). First, birds and then squirrels desert the forest where they can no longer make their harvest of cones. Martens then move elsewhere in search of better hunting. The green forest floor, made up of lilies of the valley and wood sorrel, which flourished thanks to the protection from direct sunlight afforded by the trees, is replaced by thickets of reed grass, raspberry bushes, and nettles. In short, the entire range of species is changed.

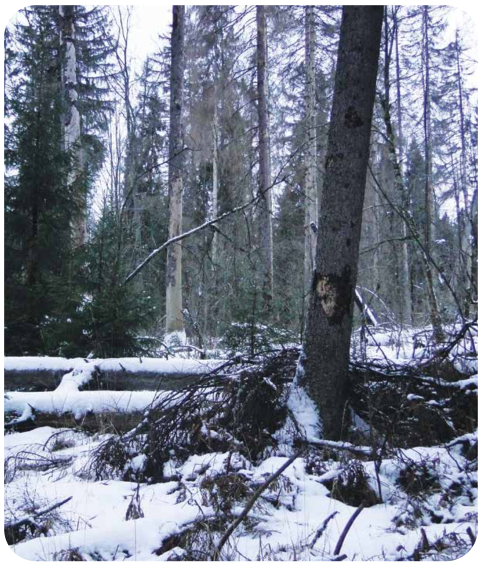
All is not lost: the displaced species can return. As happens after a serious fire, a forest of spruce will fully restore itself after one or two hundred years. But only provided that such forest has remained intact elsewhere with all its inhabitants, and abnormal fluctuations of temperature do not recur.

More recently, in September 2021, fires have destroyed more than 18.16 million hectares of Russian forest, setting an absolute record since the country began monitoring forest fires using satellites in 2001. The previous record was set in 2012, when fires covered 18.11 million hectares of forest.

Other extreme weather events – hurricane-force winds and tornadoes – can destroy forests as effectively as drought, by blowing down trees (Fig. 2.3.10). Heavy rains can also do much damage by washing away the soil or killing trees through prolonged waterlogging. Heavy falls of wet snow and the large-scale formation of ice also harm trees, and heavy showers of hail damage bark on the branches, weakening and causing them to dry out.

Figure 2.3.9

Fallen spruce after the drought of 2010



Hurricane winds in Kostroma, Russia

In June 2010, Kostroma and neighbouring regions in Russia experienced hurricane-force winds of up to 70-90 km/h. Houses and buildings were damaged, power lines were torn down, and falling trees caused accidents in towns and villages. There was extensive damage to forest plantations in the Kostroma region (Fig. 2.3.10). Researchers from Kostroma State University estimate that 21,000 hectares of forest were destroyed. Such events are occurring with an increased frequency, most recently in August 2023.

Figure 2.3.10 **The aftermath of hurricane-force winds in Kostroma region**

The history of glaciation, along with current scientific evidence and forecasts, show that forests and other natural ecosystems can adapt to the most varied climatic conditions. But this adaptation is mainly related to migration - that is, to changes in the boundaries of natural areas and vegetation types. During periods of glaciation, forests survived in a relatively small area, and large expanses of Eurasia were covered by tundra and tundra-steppe. When the climate grew warmer, forest regained its status as the dominant vegetation type. But warming of the climate today is happening too quickly, threatening not gradual, but catastrophic change of vegetation types, through the large-scale drying-out of forests with high risk of forest fires.

This makes it highly important not to let global warming reach extremes, and to work toward a gradual stabilization of the climate change on the planet.

How do forests affect climate?

We know now how climate and climate change affect forests. But this relationship also holds in the other direction: forests have an impact on climate!

For example, green forest changes the reflection of sunlight by the Earth's surface, so it affects the amount of heat absorbed by Earth. The difference in temperature between forested areas and areas without forest are especially noticeable in the winter. The sun's rays are reflected from the treeless, snow-covered plains, but the dark spaces of boreal forests reflect less and absorb more of the sun's light.

Forests help to retain moisture in the soil and affects evaporation, making the regional climate milder and wetter.

Snow cover remains longer in the forest, lessening sharp changes of temperature that occur in the springtime and reducing the risk of spring flooding by rivers.

But what makes forests particularly important for climate is the carbon cycle. Carbon dioxide released into the atmosphere by the burning of fossil fuels is the main cause of the global warming occurring today. Forests play the vital role of absorbing carbon dioxide from the atmosphere and retaining carbon in the form of various organic substances.

You may know that green plants absorb carbon dioxide and produce oxygen. This process is called photosynthesis, and it is powered by the energy of sunlight. Forests represent a dense concentration of green plants (trees, shrubs and grass) and are therefore thought to be vital for enriching our planet's atmosphere with oxygen. You often hear the term 'green lungs of the planet' used on TV and in newspapers to describe forests. Absorption of carbon dioxide and emission of oxygen are the two sides of the single process of photosynthesis, so you would think that forests must remove carbon dioxide from the atmosphere. But it is not that simple. To understand the process of exchange of carbon dioxide between the forest and the atmosphere, we need to understand how the forest stores carbon, the element that joins with oxygen to form carbon dioxide. All organic substances contain carbon. For example, nearly half of the weight of dry wood is carbon.

What is a carbon pool?

Any part of the ecosystem that contains significant amounts of organic matter is a store of carbon. Scientists call such stores '**carbon pools**'. Carbon pools can do both, take or release carbon. There are four main carbon pools in the forest ecosystem: 1) phytomass or biomass (the weight of living plants); 2) dead wood; 3) litterfall (dead leaves and branches on the forest floor), 4) organic matter in the soil. In many countries there is a much smaller fifth pool, called harvested wood products.

The **phytomass pool** consists of living plants: the trunks, branches, roots, leaves and needles of trees and shrubs, the leaves and roots of grass and moss (Fig. 2.3.11). As a rule, tree trunks account for most of the phytomass, but moss is also a major part of it in northern boreal and marshy pine forests.

The **dead wood pool** consists of dead trees and roots. The death of trees in the forest is called 'dieback' and it occurs naturally as the growing trees compete for sunlight. The smaller trees are left in shadow by the larger trees and gradually wither because they do not receive enough light for photosynthesis. This is why young forest is much thicker than old forest. But attrition can also occur in various other situations: it can be caused by forest fires, droughts, forest pests, and man-made pollution. In forests that are affected in one or several of these ways, the carbon pool in dead wood may exceed the pool in living wood.

Litterfall is made up of relatively small fragments of organic matter lying on the soil surface (Fig. 2.3.13). It consists mainly of dry leaves and pine needles, small dry twigs, flower petals, cones and other fragments that have fallen from living plants. In deciduous forests replenishment of the litterfall pool is most intensive during the autumn leaf fall, while in boreal forest it occurs more evenly through the seasons.

Figure 2.3.11

The wood in tree trunks is the biggest part of the phytomass carbon pool

Figure 2.3.12

Dead trees are part of the dead wood carbon pool

Figure 2.3.13

The litterfall carbon pool is swollen when leaves fall in the autumn

Soil pool in the forest contains significant amounts of carbon. The soil is a mixture of minerals and of organic matter, mainly '**humus**', which is a dark-coloured substance created by the gradual break-down of plant residues (litterfall, dead wood and dead roots). Carbon accounts for 58% of the make-up of humus, which is a higher share than in phytomass. The darker the soil, the more carbon it contains (Fig. 2.3.14).

The carbon stored in wood products is often referred to as the **harvested wood products carbon pool**. Some wood products, such as high-quality wood furniture and wood framed buildings, can hold onto carbon longer than if the tree had been left in the forest. Wood products are important for helping bank existing forest carbon while harvesting helps give space for replacement trees to grow.

In boreal forests, phytomass contains 21% of the carbon stock, dead wood 4%, litterfall 3%, and 72% is in the soil. So, in these forests, carbon is concentrated in the soil.

These shares are quite different in tropical forests, where living and dead organic matter accounts for 50% of carbon.

Why is the difference so large? In boreal forests most dead plants are broken down by fungi and bacteria, and this process occurs slowly. It takes many decades for the trunks of large dead trees to disappear. Because of this, the forest accumulates large pools of dead organic matter – dead wood, litterfall and humus in the soil. In tropical forests, a large part of the litterfall and dead wood is consumed by animals, especially termites. This speeds up the rate of decomposition and reduces the contribution of dead organic matter to the total amount of carbon in the ecosystem.

Figure 2.3.14

If soil is dark, it contains a lot of carbon

Carbon budget

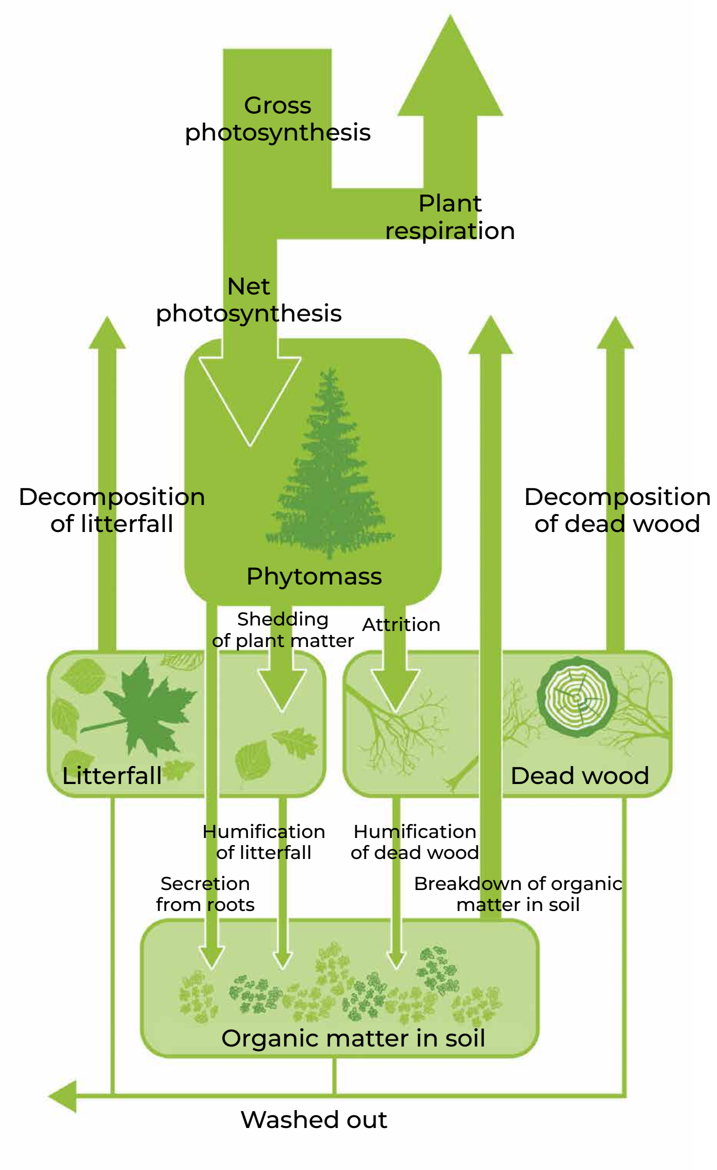
Now that we know all about carbon pools in the forest ecosystem, let's see how these pools relate to one another and the atmosphere (Fig. 2.3.15). Scientists call this system of connections a **'carbon budget'** because it is like the financial budget of a country, a company, or a family, where what comes in (income) must be matched with what goes out (spending).

The only 'income item' in the forest ecosystem is photosynthesis. The sum of photosynthesis creates organic sub- stance. The first consumers of this sub- stance are plants themselves: nearly half of it is used by plants when they breathe, releasing carbon back into the atmosphere. The remainder of the substance is called 'net photosynthesis': it replenishes the phytomass pool.

Various living organisms that inhabit a forest consume the living substance of plants: caterpillars and insects feeding on leaves; birds and rodents collecting fruits and seeds, and hoofed animals that eat grass and young branches.

Figure 2.3.15

The carbon budget of a forest ecosystem



In taiga and temperate forests, a large part of the plant life dies naturally (when a plant withers and dies or when it drops its leaves and twigs) and is then consumed by fungi and bacteria (Fig. 2.3.16). This replenishes the dead wood and litterfall carbon pools.

When fungi and bacteria breathe, the carbon **humification** of litterfall secretion from roots of organic matter binds with oxygen and returns to the atmosphere as carbon dioxide. This happens as dead wood and litterfall decomposes. A modest part of these pools is transformed into humus and replenishes the soil carbon pool (this process is called humification). Carbon also enters the soil from living plants in the form of organic substances that are secreted by the roots.

Organic matter in the soil is also broken down by fungi and bacteria with the release of carbon dioxide into the atmosphere. A part of the carbon is washed out of the ecosystem by groundwater and surface water: you must have seen autumn leaves being carried away by forest streams.

Forests that contain many mature and old trees absorb the same amount of carbon dioxide from the atmosphere as they release back into it. Carbon pools in such a forest remain constant over time. They are like swimming pools: full to the brim and incapable of taking more, except that they are filled with carbon and not water. But that is not to say that mature forests don't play a role in regulating the gas composition of the atmosphere. The point is only that they no longer actively absorb and have instead become the keepers of 'stored' carbon, i.e., carbon that can no longer contribute to the greenhouse effect.

The carbon budget of young, growing forests is different from that of mature forests. Young forests accumulate carbon, removing it from the atmosphere. This carbon builds up in pools. So, it is only young forests that deserve to be called the 'green lungs' of the planet.

Figure 2.3.16 **Tinder fungus breaks down dead wood and returns carbon to the atmosphere**

Differences in the impact of forests on the atmosphere

We have seen how young and old forests work differently: young, growing forests absorb carbon dioxide from the atmosphere and can thus partially compensate for emissions of this gas by the combustion of coal, gas, and oil. Mature forests store enormous amounts of carbon in bound form, preventing the formation of carbon dioxide, which would contribute to the greenhouse effect. So, if we want to use forests to prevent climate change, we need to: 1) plant new young forests, where there was no forest before; 2) take good care of existing forests.

In developed countries with advanced economies (the United States, the countries of the European Union, Canada, Russia, and others) there are many young forests that absorb carbon dioxide from the atmosphere and are less at risk of being destroyed for human industry. Many of these countries are also encouraging landowners to plant forests.

Because boreal and temperate forests grow and absorb carbon over many decades and sometimes hundreds of years, carbon is now being accumulated thanks to renewal of the forest in many of the places where forest cover was severely reduced during the industrialization of the last century. The restoration of pine forest along the Canadian Pacific coast is a striking example of this.

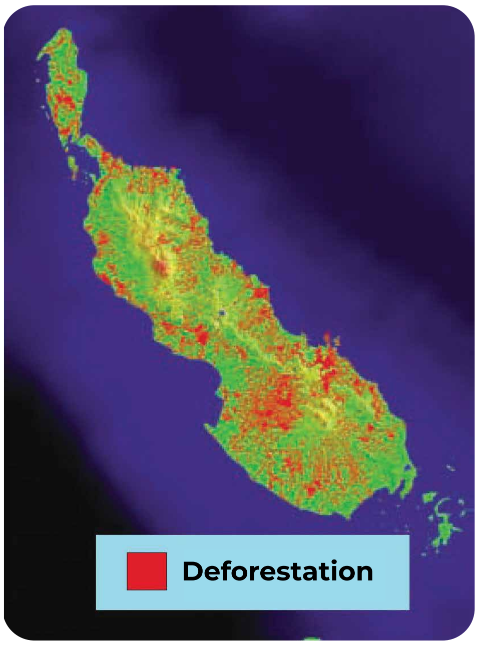
At the beginning of the century this territory was covered with huge conifer forests of Douglas Fir and Red Cedar, some of them as high as 80–90 metres. By the middle of the 20th century, these forests had been cut down, and the giant stumps of felled trees more than two metres in diameter can still be seen (Fig. 2.3.17). Since then, strict environmental laws established in Canada have renewed forests in former logging areas.

Figure 2.3.17

This giant tree stump in the forest of western Canada (British Columbia) is evidence of intensive tree harvesting in the first half of the 20th century

Figure 2.3.18

Loss of forest cover on the island of Bougainville (Papua New Guinea), 1972-2002



The situation is quite different in developing countries, especially in South America, South-East Asia and Oceania. With growing populations and economies, these countries always need more land for agriculture, factories, cities, towns, and roads. This land comes mainly from the destruction of tropical forests, and new forests that would absorb carbon dioxide are not being planted. A photograph taken in the tropical region of Argentina (Fig. 2.3.19) shows the beginning of the destruction of forest. Forest land previously belonging to the army was transferred to local government control in the early 2000s. Local government gave permission for agricultural development of the land, and the felling of trees began.

Deforestation is occurring very rapidly in some tropical regions. Deforestation in Papua New Guinea is extensive and occurs at a rate of 1.4% of the tropical rainforest being lost annually. Illegal logging is the main cause of deforestation, contributing to 70-80% of all timber exports. Between 1972 and 2002) the country lost more than five million hectares of forests, trailing only Brazil and Indonesia among tropical countries (Fig. 2.3.18). As a result, greenhouse gas emissions from deforestation in Papua New Guinea more than doubled over this 30-year period. Thanks to rainforest conservation efforts, the pace of deforestation has recently slowed to an average 0.5% annually.

About 10% of all the carbon dioxide now being emitted into the atmosphere by human action comes from the destruction of tropical forest. The United Nations programme, Reduced Emissions from Deforestation and Forest Degradation (REDD+), is a step towards a global system to reduce greenhouse gas emissions caused by deforestation in developing countries. Bilateral international projects to preserve tropical forests are being set up, for example agreements between Brazil and Norway, and Australia and Indonesia. Some developing countries, such as China, India, and Costa Rica, have their own programmes to increase the area of their forests. Overall, though, the rapid release of carbon stocks by the destruction of tropical forests remains a major concern.

Figure 2.3.19 A former forest area in Argentina

The disappearance of tropical forests

Tropical rainforests are among the most important ecosystems on the planet. Their ecosystem is the richest in species diversity. Tropical forests are a source of timber, food and raw materials for medicines. They also play a pivotal role in regulating the Earth's climate. The disappearance of tropical forests leads to the loss of fertile topsoil, loss of biodiversity and disruption of the ecological balance over large areas of the planet.

Despite all efforts, however, tropical forests are continuing to disappear rapidly, particularly in South America and Africa. About 3.6 million hectares of forest cover in South America and 3.4 million hectares in Africa have been lost between 2005 and 2010. Today tropical rainforests cover only 5% of the Earth's surface, compared with 12% 100 years ago. An area of forest larger than all of England (130,000 km^2) is being cut down or burnt each year.

In an encouraging development, deforestation has declined and net forest cover increased since 2010. Government initiatives and international moratoria were successful in reducing deforestation in the Amazon between 2004 and 2015, while forest regrowth occurred in Europe, Eurasia, and North America. But keeping deforestation rates low is challenging, given increased deforestation rates in the last four years in the Amazon and elsewhere.

One of the main causes of deforestation is the conversion of forests into agricultural land to feed a growing world population. Rainforests are often replaced by plantations to produce palm oil, soy, cocoa, rubber, and coffee as well as for cattle farming. Uncontrolled mining operations are another threat to tropical rainforests in South America. These are all leading causes of tropical forest loss, destroying some of the most biodiverse places on Earth, home to species including jaguars, sloths, orang-utans, toucans, and lemurs.
Such major destruction of forests can be irreversible. If the felling of trees is limited to a small area, then the forest will return after a few years, but if a large area of forest is cut down, it may never reappear: heavy rain will wash away essential nutrients in the soil and the sun will burn the top layer of soil, so that only weeds can grow.

What can be done to save the forests? First, developing countries with large areas of tropical forest (primarily Peru, Ecuador and Indonesia), as well as Brazil, must be encouraged to pursue other economic activities, which do not involve deforestation. Otherwise, the destruction of trees will continue for mining and food production.

Economic incentives and regulations can help to reduce deforestation and prevent forest loss. Brazil had considerable success at reducing deforestation in the Amazon in the late 2000s and early 2010s. Environmental laws, a new Forest Code, improved surveillance of slash-and-burn illegal logging and a soya moratorium in the Amazon were credited with the fall. However, there have since been large spikes in deforestation in the world's largest rainforest due to lack of law enforcement. Similarly, Indonesia's recent success in slowing deforestation with a moratorium on palm oil expansion is fragile for the same reasons: the economic incentives to clear forest have not changed.

How to manage the carbon balance of forests and help forests adapt to climate change

The carbon balance of forests depends on many factors, the most important of which are human activity, disasters (forest fires, plagues of pests, etc.) and climate change. The carbon balance of forests can be managed: if the felling of forests for timber and other purposes is reduced, forests will absorb more carbon from the atmosphere.

One project in the far east of Russia aims to halt large- scale logging in the cedar and deciduous forests of the Bikin River Basin, where only local inhabitants will be allowed to cut timber (Fig. 2.3.20). The project encourages residents to develop traditional forms of forest management, including the collection of pine nuts, berries, mushrooms, ferns and herbs.

It is also vital to reduce the damage caused by forest fires, most of which are started by people failing to put out picnic fires, throwing cigarette butts on dry litterfall or lichens, and setting fire to dry grass (Fig. 2.3.21), actions defined as 'being careless with fire'. We have all been warned to protect the forest from fire, but the warning acquires a new urgency in the face of climate change. If you can teach your friends not to burn grass or set fire to summer fluff, and to carefully extinguish the campfire after a family outing in the forest, you will be doing your part to prevent climate change.

Figure 2.3.20

Cedar-deciduous forest
in the Bikin River Basin

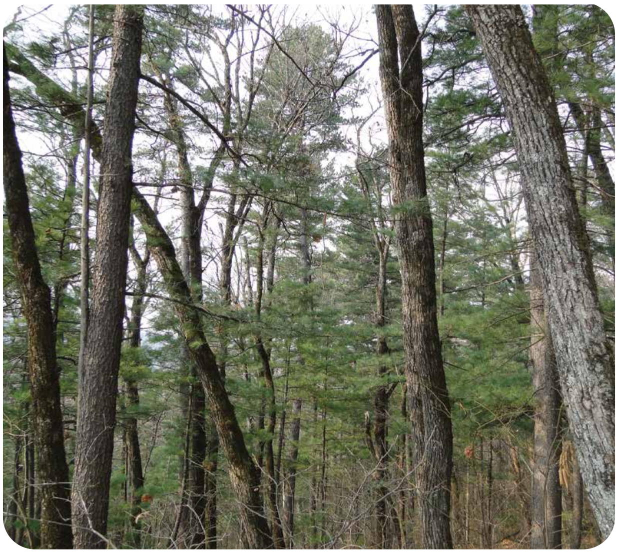


Figure 2.3.21

Dry grass burning,
set alight by people

In general, scientists distinguish between adaptation for natural and for managed forests. Adaptation for natural forests includes conservation, protection, and restoration measures. In managed forests, adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires. Forest management is a popular strategy to cope with drought, reduce fire risk, and maintain biodiverse landscapes and rural jobs. Restoring natural forests and drained peatlands and improving the sustainability of managed forests enhances the resilience of carbon stocks and sinks.

The IPCC AR6 notes that successful adaptation strategies for forests in Europe and Russia include altering the composition of tree species to enhance forest resilience. Diversifying tree species and increasing conservation areas reduce vulnerability to pests and pathogens, strengthen resistance to natural disturbances, and may increase carbon sequestration, biodiversity, and water quality. Active management approaches can limit the impact of fires on forest productivity. These include reforestation, fuel reduction management, prescribed burning, changing from conifers to deciduous, less flammable species, recreating mixed forests and agroforestry.

QUESTIONS

1 What is taiga or boreal forest?

2 What species of tree is dominant in Eastern Siberian taiga and why?

3 How has the border of the forest-tundra shifted in recent decades and why?

4 If temperatures rise by 4°C before the end of this century, how will they affect forests?

5 How do human activities affect forests?

6 What are the major carbon pools in the forest ecosystem?

7 Can plants breathe?

8 Which organisms break down dead plant residues?

9 Can mature and old forests remove excess carbon dioxide from the atmosphere?

10 Why are tropical forests losing their carbon stocks?

11 What kind of climate adaptation measures, mentioned in this and other chapters, are recommended to address climate impacts on European and Russian forests?

TASKS

1

Experiment

Objective: To find out which trees and shrubs are most sensitive to warming.
Materials: branches of trees (before leaves appear), vases with water.

The procedure: The experiment is carried out a few weeks before snow starts to melt in your region. Cut a few branches from various trees and shrubs (birch, elm, willow, poplar, maple). Put them in vases with water and observe them regularly. Take note of how the buds grow, when they open, and how the leaves grow. Also measure how buds develop on the trees themselves. After leaves have appeared on trees, make a chart to plot the growth in the size of the buds and the leaves indoors and outdoors. Find out which three species are more sensitive to a warmer environment (which of them react faster to warmth).

2

Experiment

Objective: To find out which tree species contain more carbon in their wood.
Materials: Pieces of various types of wood (oak, spruce, birch, aspen and others), a ruler, scales.

The procedure: Measure each piece of wood to calculate its volume (multiply the length by the width by the height) and weigh it. Divide the weight of each piece by its volume to find out the weight in grams of a piece of wood with sides of one centimetre. Divide the result by two to get the weight of the carbon in the piece of wood. Discuss the result and decide which tree species has the greater carbon pool. You can then judge which species is best to plant to reduce the greenhouse effect.

3

Experiment

Objective: To compare the amount of oxygen and carbon dioxide emitted by plants in the light and in the dark.

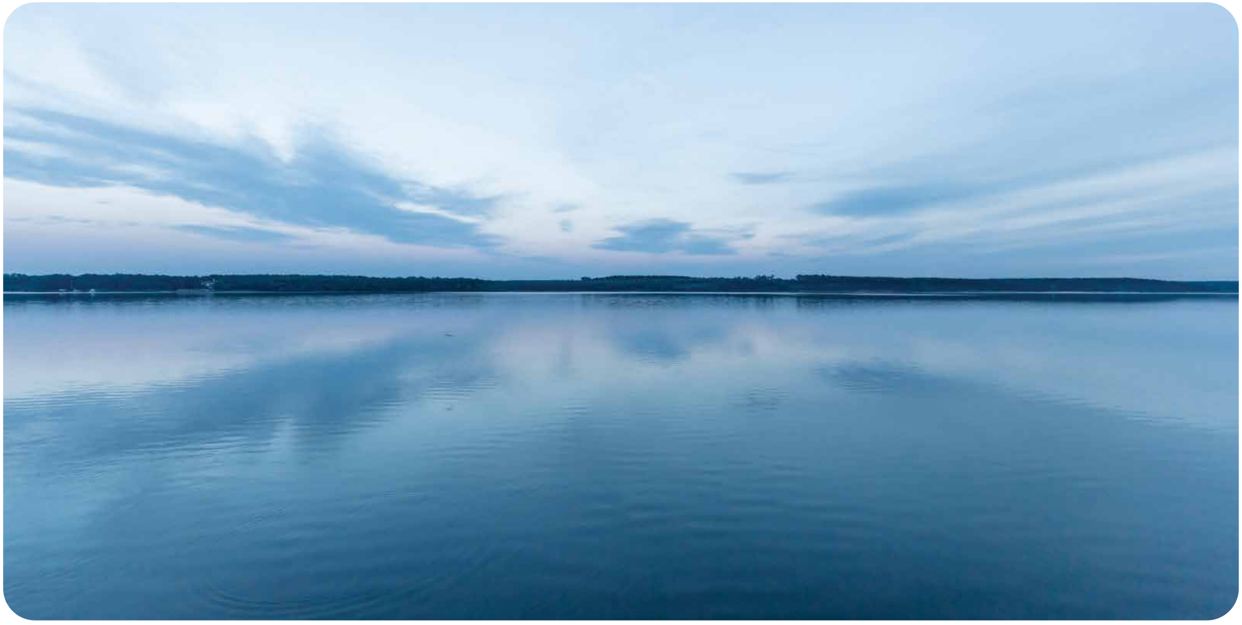
Materials: Two large glass containers with air-tight lids and containing water (about a third of the volume of each container), cuttings of plants with large leaves, a splint, matches.

The procedure: Place a plant cutting in each container and seal it. Put one container in a warm, bright place, and cover the other with a cloth that keeps out the light. After one or two days use a lighted splint to see in which of the containers the flame burns brighter: do this immediately after removing the cover, until the gas in the container has been diffused. Notice the bright flash of flame on the splint you put into the 'light' container immediately after removing the cover and notice how the flame dimmed when you put the splint into the 'dark' container. Now you know that a plant produces more oxygen than carbon dioxide when it is in the light, but more carbon dioxide than oxygen when it is in the dark.

2.4 How climate change affects **water resources**

Water in the natural world

Water has a special place among the vast number of chemical compounds that are found on our planet. It flows from the taps, we boil it in kettles, and it fills rivers, lakes, seas, and oceans.



Water can exist in various states: solid, liquid and gas. When the air temperature is below 0°C, water freezes to a solid state and becomes ice. Water comes out of taps in a liquid state, and the jet of steam from a boiling kettle is water in its gaseous state. Incidentally, the water in the clouds that we see in the sky is very often in three states at once, and that is what determines the different forms that clouds can take.

Figure 2.4.1 Noctilucent clouds in Sweden

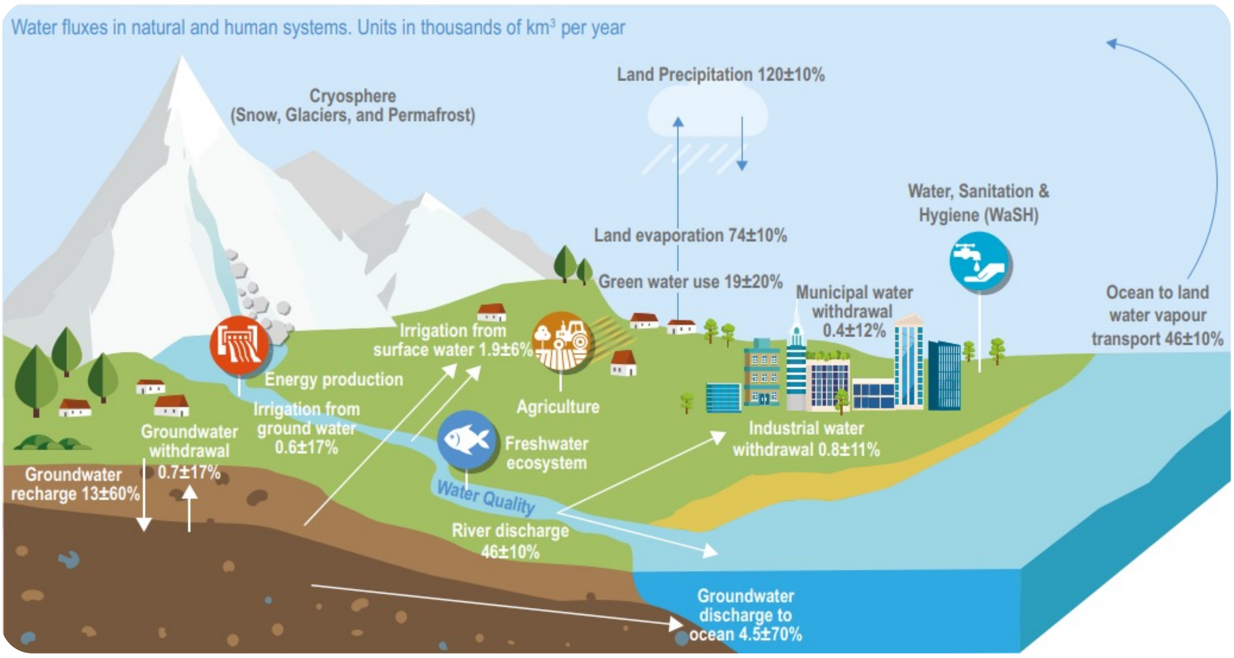
Noctilucent clouds are a particularly beautiful type of atmospheric formation. They are at an altitude of 76–85 km above the earth and are formed of nothing but ice crystals, which determines their fantastical appearance. Noctilucent clouds can only be seen at night in polar latitudes, when they are illuminated by the sun, which has already fallen below the line of the horizon.

The science that studies water is called **hydrology**. It is believed that the first hydrological studies were carried out 5,000 years ago by the ancient Egyptians on the River Nile: they measured the height of seasonal floods by making marks on the walls of buildings, rocks, or steps down to the river.

If there was no water on our planet, there would be no life: many types of plants and animals are composed in large part of water. For example, a human body is 60% water on average. This share depends on age: the body of a newborn infant is 86% water, but that of an elderly person only 50%. It is very important for people to drink enough water. A person can live without food for about a can only survive for three to ten days without water.

Water on Earth takes many forms that are in constant movement and altogether form the water cycle. The water cycle (Fig. 2.4.2) is the process by which water circulates between the Earth's oceans, atmosphere, and land, involving precipitation as rain and snow, drainage in streams and rivers, and return to the atmosphere by evaporation and transpiration. The water cycle is affected by both climatic and non-climatic factors.

Figure 2.4.2 **The water cycle, including direct human interventions**

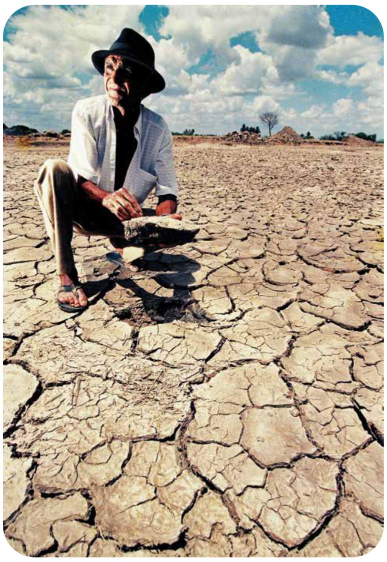


All parts of the water cycle on Earth that are used or could be used by human beings are called 'water resources'. They include all water in rivers, lakes, canals, reservoirs, seas and oceans, groundwater, soil moisture, frozen water (ice) in mountain glaciers and polar ice caps, and even water vapour in the atmosphere.

More than 97% of all water on the planet is in oceans and seas. The water in the ocean is salty and not suitable for drinking. Less than 1% of the total volume of water on the planet is fresh water in rivers, lakes, streams, and other surface water bodies. That doesn't seem like much, but there is another vast reserve of fresh water: the glaciers and ice caps of Antarctica and Greenland. They account for 2% of all the water on Earth – nearly eight times more than all the water in rivers and lakes combined.

Preserving the planet's reserves of fresh water is one of the major environmental challenges facing us today: without these reserves mankind cannot survive.

Climate change and the increasing demand for food and sanitation from the world's growing population have created water shortages in many countries. Since the beginning of the 20th century, the world's population has grown from 1.6 billion to more than eight billion. The rapid growth of population, changes in lifestyle and agricultural expansion have all increased water use in most countries. About 70% of all freshwater is used to water fields for growing crops. UN experts estimate that by 2050, nearly 90% of the world's freshwater resources will be needed for food production.



UN experts also point out how unevenly drinking water is distributed across the continents: Asia is home to 60% of the world's population but has only one-third of the world's water resources. According to the World Health Organization, in 2020, around one in four people lacked safely managed drinking water in their homes and nearly half the world's population lacked safely managed sanitation, most of them in Africa.

Goal 6 of the UN Sustainable Development Goals adopted in September 2015 is on clean water and sanitation, with one of its targets aimed at achieving "universal and equitable access to safe and affordable drinking water for all' by 2030.

How does climate change affect water resources?

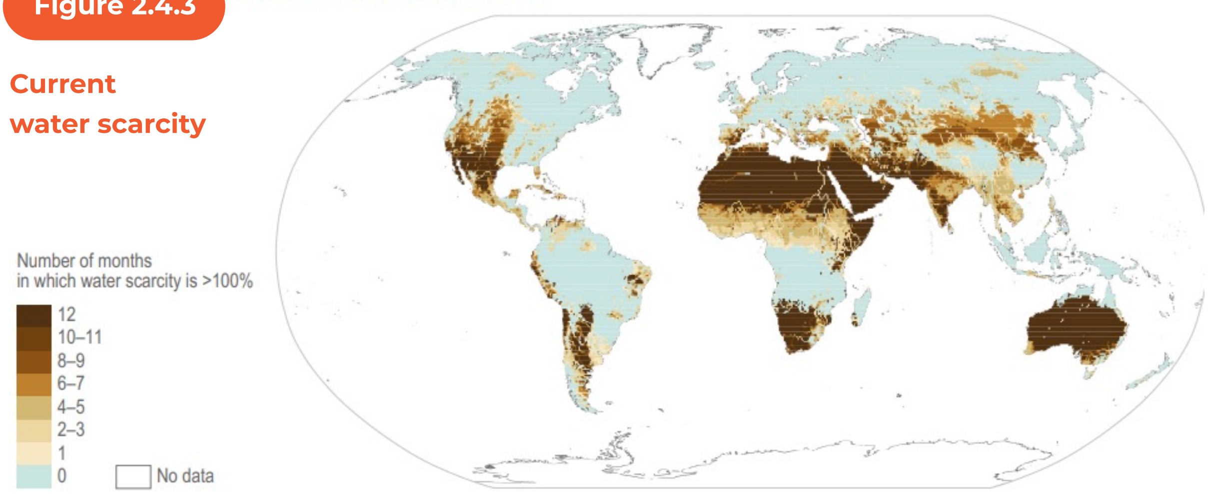
All the sources of fresh water on Earth (rivers, lakes, swamps, snow, glaciers, groundwater) are intimately related to climate. To a certain extent they are all a product of climate, although, of course, they all depend on different components of the natural world.

We already know that warming of the climate in many parts of the world will probably increase the frequency of heavy rains, causing disastrous flooding. In other areas, precipitation is expected to decrease, so that extreme droughts will become more frequent. Unfortunately, very wet regions will become even wetter, while dry regions, especially in the central parts of continents, will suffer increasingly from the effects of drought.

Scientists note that climate change will significantly affect water resources leading to water shortages in arid regions of the world, most notably the Mediterranean countries, the western United States, Southern Africa, and northeast Brazil. They define the mismatch between the demand for fresh water and its availability as water scarcity. It is estimated that around half of the world's population, or four billion people, live under conditions of severe water scarcity for at least one month per year (Fig. 2.4.3). Nearly half of them live in India and China. Although regions with high water scarcity are already naturally dry, human influence on climate is reducing the availability of water in these and in many other regions. At 2°C warming, globally, 800 million to three billion people are projected to experience chronic water scarcity due to drought, and up to approximately four billion at 4°C warming, considering the effects of climate change alone, with present-day population.

Figure 2.4.3

Current water scarcity

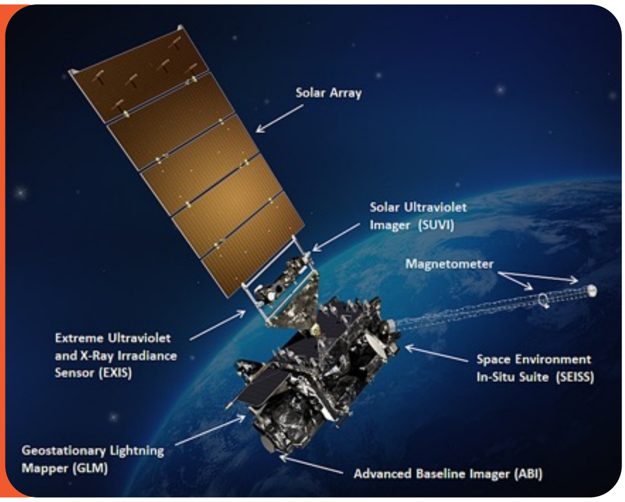


Note: water scarcity is defined as mismatch between the demand for fresh water and its availability. This is why when we speak of regions with water scarcity we usually indicate time period when water scarcity is greater than 100%.

Climate change will also significantly affect glaciers and snow cover. Weather satellites (Fig. 2.4.4) show that the area covered by snow in the northern hemisphere has significantly decreased over the past 45 years. The reduction of snow cover in mountainous areas has been most noticeable in western North America and in the Swiss Alps, mainly at low altitudes.

Figure 2.4.4 United States weather satellite of the meteorological-satellite service

Weather satellites are sent into orbit around our planet to obtain meteorological data, which can be used for weather forecasting and climate observation. Other satellites can transmit TV signals, operate vehicle navigation systems, and much more.



Changes in the amount and the cycle of precipitation, the melting of mountain glaciers and the general rise in temperatures on the planet all lead to changes in the volume of water carried by rivers. Typically, river flow changes from season to season, but there are certain long-term patterns now being affected by climate change. These changes could result in major floods that inundate riverside settlements or, conversely, dry up a riverbed. In temperate latitudes today, rivers freeze later and lose their ice earlier. These changes need to be considered in economic planning, since rivers are vital to the economy of many countries. They are arteries for the transportation of goods and passengers, a source of hydroelectric power, and reservoirs of fresh water for drinking and for irrigation.

DRAINAGE BASIN
is an area of land from which all surface water and ground- water flows into one water body, including its various tributaries.

Figure 2.4.5 The Amazon River in South America has the largest drainage basin in the world, covering seven million km²

Figure 2.4.6 The Nile is the world's longest river

The countries that have the largest supply of fresh water in the world are Brazil (the world's greatest river, the Amazon, flows through its territory), followed by Russia and Canada. However, the distribution of freshwater around the world is extremely uneven. Even in water-sufficient countries like Brazil or Russia there are areas that already experience water stress (Fig. 2.4.9). This natural 'injustice' will grow more marked over time due to climate change: regions that already suffer from water shortages will become even more arid (Fig. 2.4.3 and 2.4.8).

Figure 2.4.7

Lake Baikal in Siberia is the largest reservoir of fresh water on Earth

Figure 2.4.8 **Projected decline in water supply in United States counties: (a) without climate change effects and (b) with projected climate change effects**

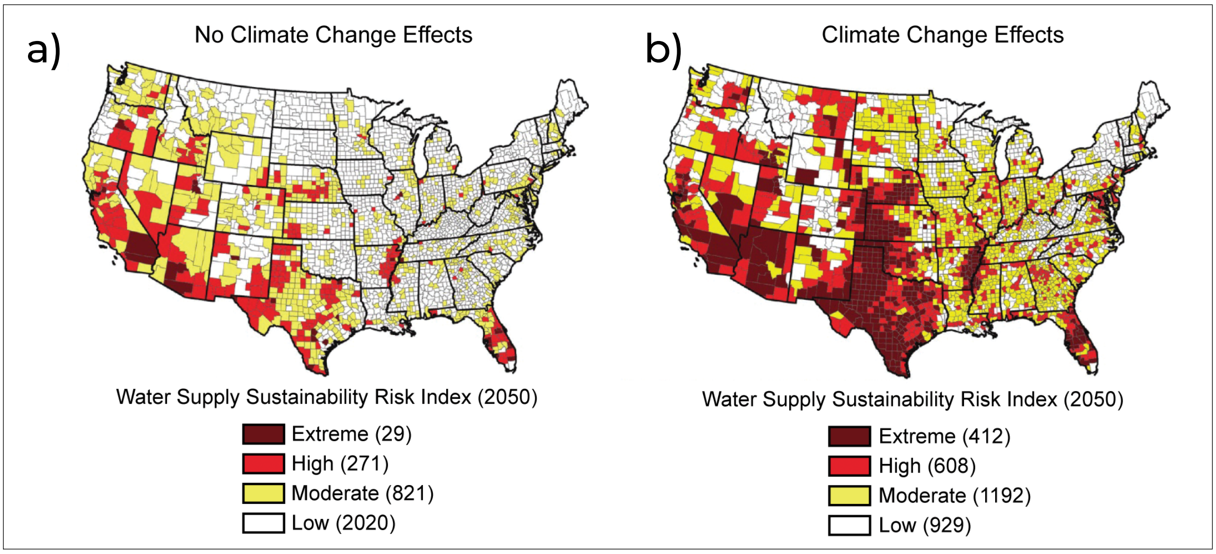


Figure 2.4.9 **Water shortages are already a problem in Southern Russia**

How can the risks be reduced and adaptation enabled?

Until recently, it did not occur to people responsible for water management that climate change would force them to review the whole system for managing water resources. Unless proper measures are taken in good time, the damage caused by sudden and severe droughts, floods or reduction of freshwater resources could be enormous. Scientists note that adaptation to water-related risks and impacts make up much of all documented adaptation worldwide and propose a range of measures.

The first thing needed is improved weather forecasting to help predict the probable occurrence of severe weather events in advance.

Second, technology and engineering solutions can reduce risks to people and infrastructure, from the construction of dams and reservoirs along rivers to help regulate their flow, to the creation of structures along riverbanks to protect communities from severe flooding.

Third, we must improve water management systems and change consumer behaviour to reduce water consumption. This can be done, for example, by harvesting rainwater or by using the same water twice for different needs. Special installations to convert salt water into fresh water by desalination are also promising (Fig. 2.4.10). Most of all, we must remember to use water efficiently.

Figure 2.4.10 A seawater desalination plant in the United Arab Emirates

Fourth, we can apply nature-based solutions more widely to adapt to water scarcity resulting from climate change. Such solutions rely on natural processes to enhance water availability and water quality, and reduce risks associated with water-related disasters while contributing to biodiversity. Examples include the use of natural or semi-natural systems such as wetlands and healthy freshwater ecosystems to supply clean water, regulate flooding, enhance water quality, and control erosion. Cities like New York and Copenhagen have integrated large-scale investment plans comprising nature-based solutions in urban planning to deal with high-impact extreme precipitation events. This is a growing trend: one in three cities use nature-based solutions to address water-related climate hazards, according to the Carbon Disclosure Project database.

Harnessing indigenous and local knowledge: how the ancient Indians of Latin America adapted to a changing climate

The indigenous peoples of Central and South America lived mainly on crops they grew around their settlements. In highland regions, where many ancient Indian civilizations were focused, food production was limited due to the uneven distribution of water resources. There was no shortage of water during the rainy season, but how did these ancient peoples manage during the dry season?

The main source of water in the dry season was rivers flowing from mountain glaciers, but they only supplied settlements along the river valleys. The ancient Indian tribes invented a range of technologies and contrivances to ensure year-round supply of water in the mountains.

The Indians learnt to catch, filter and store rainwater, to build surface and underground irrigation channels, and invented devices for measuring the amount of water they had in storage. They even connected the river basins of the Pacific and Atlantic oceans. They also developed a system of weather forecasting, which could predict when the rainy season and the dry season were likely to begin, so that they could better organize the sowing and harvesting of crops.

The indigenous peoples of America used their engineering skills to straighten riverbeds and build bridges, both hanging bridges and bridges with supports. They had piped water for everyday use and for religious ceremonies. The priests of the Chavin culture channelled water through pipes inside their temples to obtain a sound like the roar of a jaguar, an ani- mal which they worshipped as a god.

Using an ingenious technique, they used water to cut blocks of stone used in construction. Water was channelled into specially made channels in the stone and left to freeze at night in sub-zero temperatures, gradually creating cracks that divided the stone into the regular shapes required for building.

The Indians of Central and South America, who lived on a vast territory from modern Mexico in the north to Chile and Argentina in the south, were thus pioneers in the use of various technologies that can be used today, melded with the latest scientific knowledge, in adapting to adverse and unpredictable climate conditions.

Figure 2.4.11

Water collection system in Nazca regions (southern coast of Peru) for underground aqueducts and distribution of groundwater

QUESTIONS

1. What do we call the science that studies water?

2. Which country has the largest supply of fresh water in the world?

3. Which regions of the world will be particularly affected by water shortages and why?

4. What is the name of the river basin where your hometown is located and what sea does it flow into?

5. List at least three adaptation measures that help to reduce risk from climate change on water resources.

TASK

Find the Amazon River on a physical map of the world. Measure its length and the area of its drainage basin and compare it with the major river in your country.

2.5 How climate change affects **agriculture**

One might think that climate change would help agriculture in northern countries. But a warmer climate is not necessarily better. If it gets warmer in regions where it was previously too cold to grow wheat, it will also get warmer in regions where there was already an ideal climate for agriculture, and more heat means less moisture and low productivity. So, it will become much more difficult (if not impossible) to grow crops in areas where they have been cultivated for centuries and where specific traditions of agriculture have taken shape.

So, the conditions for agriculture will get better in some places but worse in others, and it is difficult at this stage to predict the outcome of such a 'global shake-up' for various countries.

It is important to remember that climate is not the only natural factor with impact on agriculture.

For example, one of the main cereal crops in North America, Europe and Siberia is winter wheat. Climate warming means that the zone with ideal climatic conditions for its cultivation will move to the north. But the soil in these new regions is not as good as in the regions where winter wheat is grown today. Improving the soil quality in more northerly regions will require much work and be very expensive.

Winter wheat is sown not in the spring, like other wheat, but in late summer and early autumn, so that the seeds have time to germinate and take root before the winter snows come. The wheat resumes its growth in the warmth of spring and ripens somewhat earlier than crops that were only sown in the spring.

Climate change affects fruit and vegetable production. Stone fruits, particularly cherries, require cold hours to bear fruit. Too few cold nights, and the trees are less likely to achieve successful pollination and will produce fewer fruits. Unusually timed cold weather can be just as disastrous. In 2023, the ‘Peach State’ of Georgia in the USA lost more than 90%of its annual peach crop after abnormally warm weather in the winter, followed by a late-season freeze.

Countries with temperate and more severe climates, such as Canada and Russia, could face another challenge in the form of increased competition between forestry and agriculture. Climate change will make it possible to turn over land now occupied by forests to agriculture, which could speed up the felling of forests. Even in areas with borderline conditions for agriculture (in the extreme north of the agricultural zone), productivity from one hectare of land under crops is still greater than from one hectare of forest land. So, much thinking is needed before new territories are turned over to agriculture.

Agriculture everywhere in the world will have to adapt to the new climatic conditions. Experts at the Food and Agriculture Organization (FAO) believe that crop yields in many parts of the world will decline after 2030 due to climate change. Forecasts indicate that the most serious consequences are likely to occur in tropical regions, where rainfall is likely to decrease further.

The increasing occurrence of droughts, floods and rainfall fluctuations in sub-Saharan Africa will make feeding the local population one of the major challenges of the coming decades. World Bank experts calculate that a reduction of rainfall and an increase in average global temperatures by 1.5–2°C will lead to a 40-80% loss of land suitable for maize, millet, and sorghum crops in sub-Saharan Africa by the 2030-2040s.

In Mexico, drought is reducing the extent of land suitable for growing maize, the country’s main agricultural crop.

Cereals are a highly important group of plants, producing grain, which is a staple food of people, as well as a raw material for many industries and feed for farm animals. Cereal crops include wheat, rye, rice, oats, barley, maize, sorghum, millet, buckwheat, and many others.

The principal cereal crop in South-East Asia is rice, which is mostly grown in the deltas of large rivers. As water levels rise in the ocean because of climate change, low-lying sections of rivers are becoming salty, which may lead to loss of crops. Parts of the Mekong Delta in Viet Nam, which is one of the world's centres of rice cultivation, are particularly affected by the rise in sea levels. Even a 30 cm rise in the level of the ocean can reduce rice crops by 11%.

In summary, agriculture is threatened by climate change impacts such as the rise in temperatures, changing rainfall patterns, the rise in sea levels (affecting coastal lowlands) and frequent droughts and floods, especially in areas prone to natural disasters. These changes are greatly affecting agriculture, and food security is an increasingly serious problem.

The concept of **food security** requires that all people always should have access to safe, nutritious, familiar, and tasty food to promote an active and healthy lifestyle.

FAO has estimated that 2.3 billion people, or 28% of the global population, faced food insecurity as of 2021, exacerbated by the effects of the COVID-19 pandemic. India, Pakistan, and the Horn of Africa were particularly affected due to losses from extreme weather events. Extreme heat in India and Pakistan led to a decline in crop yields which, combined with a ban on wheat exports and restrictions on rice exports by India, posed a threat to international food markets and countries already affected by food shortages. Monsoon rains led to unprecedented flooding in Pakistan, with an increase in water-borne diseases, which spread across the most vulnerable and food-insecure regions. In Ethiopia, Kenya, and Somalia, an estimated 22.5-23.4 million people faced food crisis or food insecurity due to drought and other factors. Major cuts in food assistance affected 75% of the total refugee population.

Agriculture is the main source of income for one-third of all working people in the world. In some countries in Asia and Africa, more than half the population is engaged in agriculture. Climate change reduces the volume of food production, which in turn lowers incomes from agriculture. And if heat and drought mean that food, in short supply, is prepared in dirty dishes by dirty hands and cannot be properly stored, it becomes a hazard to human health.

So, even northern countries cannot expect climate change to bring benefits for agriculture, free of any disadvantages; and those who live in temperate or colder climates can hardly expect to be growing oranges in their backyards in the future. Climate-smart adaptation strategies that will sustain agriculture and the people who work in it have become an urgent priority.

What are the best means of adaptation in agriculture? Most adaptation approaches in agriculture rely on efficient use of water resources and focus primarily on increasing the efficiency of irrigation systems. This includes using drop irrigation, expanding irrigated areas, collecting, and using rainwater for irrigation, adjusting irrigation timings, and shifting from rain-fed to irrigated agriculture.

Other adaptation options related to water resources include the restoration of catchments of rivers and integrated water management schemes. Options specific to agriculture include promoting sustainable agriculture and agroforestry, diversifying plants and livestock, changing crop patterns and crop systems by planting heat-resistant and drought-resistant plants, and changes in agricultural practices, such as planting trees along field edges to serve as wind breaks, installing anti-hail nets and building more greenhouses.

Scientists are warning us that crop irrigation, adjusting planting times, and changing crop patterns and systems may increasingly reach adaptation limits as we move above 1.5°C and 2°C in global warming. This particularly applies to Africa, where adaptation becomes much less effective with an increase of 1.5°C.

Figure 2.5.1 **Smart irrigation systems as a step ahead for water conservation and adaptation to climate change**

QUESTIONS

1 What is the difference between spring and winter wheat?
Which is better to plant in your region and why?

2 What cereal crops grow in your region?
Are they threatened by climate change?

3 Why do rising sea levels represent a threat for rice production in South-East Asia?

4 What is food security? Explain it using an example.

5 What percentage of people around the world are engaged in agriculture?

6 What kind of adaptation measures - mentioned in this chapter and others - are recommended to address climate impacts on agriculture?
How do these measures relate to water resources?

TASK

With the help of your geography teacher, make a list of major crops that are cultivated in your region.

Find information on the yield of these crops in your area in recent years. Is it increasing or decreasing? Have there been crop failures during this time and what caused them?

Think how climate change might affect the yield of these and other crops in your region. Could new climate conditions make it possible to grow other crops?

2.6 How climate change affects **coastal regions**

About 40% of the world's population lives within 100 kilometres of the coast. Many of the world's largest cities, ports and tourist zones are located on or near seacoasts, which account for more than 70% of total world production.

Coastal areas are closely linked with regions far inland. Impacts on coastal zones seriously affect the economy and living conditions, even in places that are far away from them. Coastal zones are highly vulnerable to the effects of climate change. The main threats to them are from rising sea levels, more intense storms that cause flooding and shore erosion, and more frequent extreme weather events.

The rising level of the world ocean

The level of the world ocean has been rising steadily for over 100 years, mainly because of global climate change. It rose by 15-25 cm, an average of 1-2 mm per year, between 1901 and 2018. That may not seem like much, but it presents a real danger for countries where the land is not much above sea level (or even below it).

The IPCC says that the rise in the level of the world ocean since the middle of the 19th century has been faster than the average in the previous 2,000 years. Since 1901, sea levels have been rising at an increasing rate. The average rate of sea level rise was 15-25 cm, or 1-2 mm per year between 1901 and 2018, increasing to 4.62 mm per year for the decade 2013-2022.

Human-induced climate change is mainly behind the rise in sea levels, and is caused principally by:

1. Thermal expansion of water: as temperatures increase, water expands and takes up more space.

2. The melting of glaciers in Greenland and Antarctica, which swells water flows into the world ocean.

In forecasting climate change, scientists use sophisticated mathematical models, which take account of the variety of factors that lead to climate change. Of course, these models cannot predict precisely by how many centimetres sea levels will rise in the next 30, 50 or 100 years. Though they apply scenarios that say that compared with 1995-2014, the level of the world ocean will rise between 15 and 29 cm by 2050 and between 28 cm and 1.01 m by 2100. Over the next 2000 years, the level of the world ocean will rise by about two to three metres if warming is limited to 1.5°C and two to six metres if limited to 2°C.

The expected rise in sea level by the end of this century represents a serious threat to coastal zones, the people living there, coastal infrastructure and coastal ecosystems, particularly small coral islands and the low-lying Pacific coast of South-East Asia. The rise will be uneven and is expected to be much greater in the tropics, where the 22nd century could see rises of one to three metres, followed by an increase of five to 10 metres from current levels in the following century.

High population growth and urbanization in low-lying coastal zones will be the major driver of risks resulting from sea level rise in the coming decades. By 2030, 108–116 million people will be exposed to sea level rise in Africa (compared to 54 million in 2000), increasing to 190–245 million by 2060 (medium confidence). By 2050, more than a billion people located in low-lying cities and settlements will be at risk from coast-specific climate hazards.

The Netherlands prepare for a climate shock

The Netherlands are very low-lying. A large part of the land in this small but highly industrialized country was originally obtained by draining coastal regions.

The Dutch have been developing technologies for the removal of water from their swampy plains for many centuries. Innovative Dutch engineers have long foreseen the threat posed by rising sea levels and have improved the design of hydraulic structures, which can hold back the advance of the sea.

Figure 2.6.1

Windmills were used to pump water from lakes

Figure 2.6.2

Afsluitdijk in The Netherlands is the biggest dam in Europe

Will coastal regions be swallowed up by the sea?

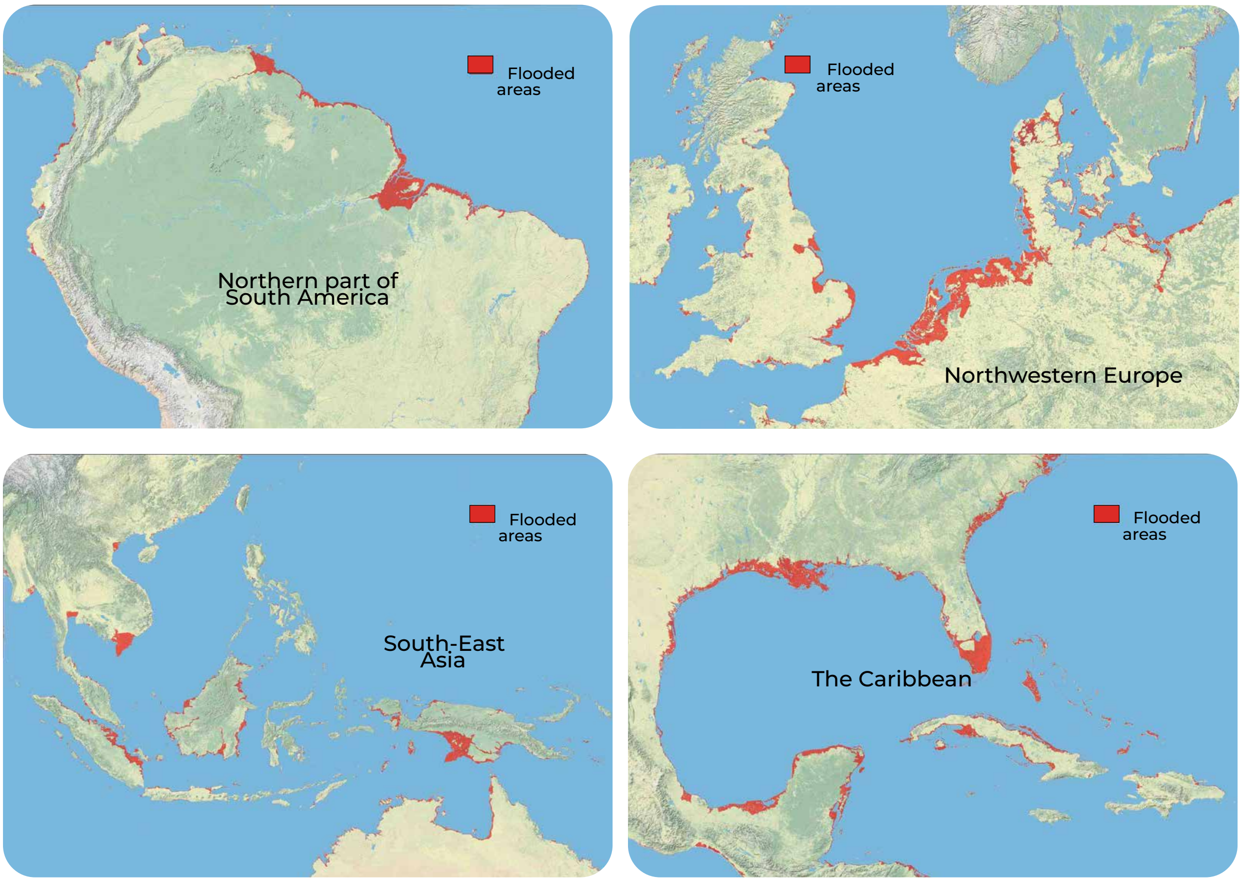
Coastal plains will be flooded because of rising sea levels, coastlines will be gradually swallowed by the sea, and fresh water supplies to coastal areas may break down. These changes can be catastrophic for densely populated coastal countries like Bangladesh, Nigeria, and Indonesia. Several major cities the world over are at risk from rising sea levels, including Shanghai, Bangkok, Mumbai, Jakarta, Buenos Aires, Rio de Janeiro, Miami, and New Orleans.

A rise in sea levels by 1 m will flood up to 15% of arable land in Egypt and 14% of arable land in Bangladesh, forcing millions of people to resettle. Salt sea water may infiltrate coastal groundwater, which is the main source of fresh water in many parts of the world.

In China, forecasts suggest that even a sea-level rise of 0.5m will lead to the flooding of about 40,000 km^2 of fertile plains. Low-lying plains and the lower reaches of major rivers such as Yellow River and Yangtze River will be particularly vulnerable. The average population density along such rivers is sometimes as high as 800 people per km^2.

In many of the Small Island Developing States (SIDS), the land mass rises only a few dozen centimetres above sea level. They could be submerged by the rising ocean, and their inhabitants forced to seek refuge in other countries.

Figure 2.6.3 **Forecasts of coastal flooding on different continents, assuming a rise of sea levels by 5 m**



Storm warning

Storms have recently become more frequent in coastal areas and at sea. Extreme storm winds, whether near the coast or in the open sea, cause **'storm surges'** – a sudden rise in water levels in water bodies that are semi-open to the sea (bays, the lower reaches of rivers). Storm surges attack coastal regions and are often accompanied by extreme precipitation and flooding, threatening the passage of ships, work on oil and gas platforms and seaside tourism, as well as causing coastal erosion.

Figure 2.6.4 Storms have become more frequent in coastal areas

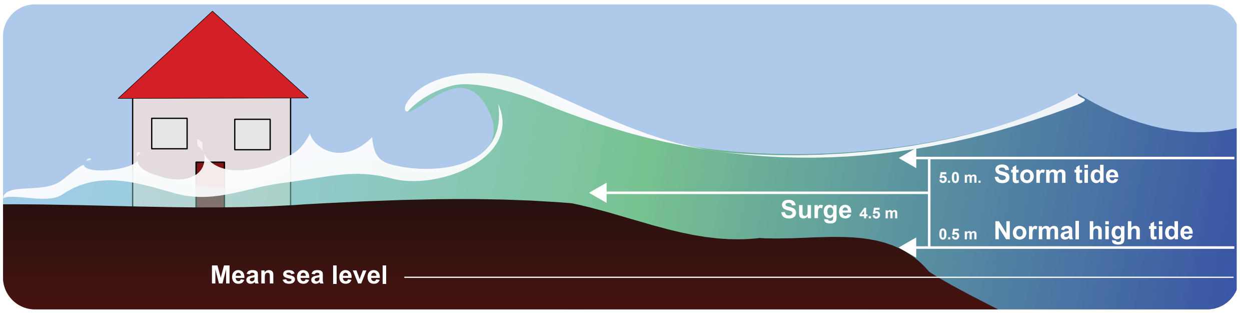
Tragedy in the Philippines

In November 2013, the Philippines suffered a disaster comparable in scale to the tragedy in Japan two years earlier, when the latter country was hit by a giant tsunami wave caused by an undersea earthquake in the Pacific Ocean. The Philippines is an upland archipelago, which often bears the brunt of typhoons coming from the Pacific Ocean; as such, the Philippines effectively protects the Asian continent behind it. Such was the scenario in 2013.

First the Philippines was struck by a super typhoon Haiyan (known in the Philippines as Yolanda), which claimed 6,300 lives; and then it was hit by a second storm, Zoraida. Authorities said the disaster affected almost seven million people in the country (the freak weather destroyed 21,200 homes and damaged 20,000).

The catastrophic impact was from the storm surge reaching up to five metres – as high as two storeys – in some areas; and there was no dam to protect the coastline.

Figure 2.6.5 Storm surge effect



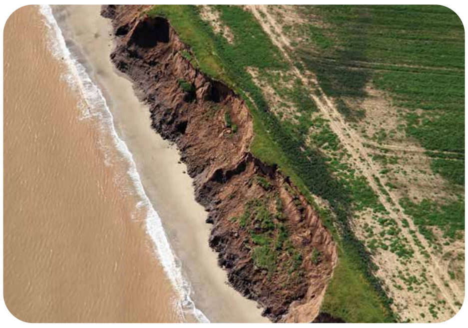
Erosion and destruction of coastline

Erosion and destruction of coastline by the sea is another consequence of rising sea levels (Fig. 2.6.6–2.6.9). Erosion is a particularly serious problem along the Arctic coastline, which was previously protected by ice, but is now losing ground rapidly as the ice cover has lessened and storm weather has become more frequent. The coast in the Arctic is retreating by as much as 10–25 metres or more each year in some places.

Figure 2.6.6 Destruction of coastline on the shores of the New Siberian Islands in the Arctic

Of course, the erosion of seacoasts by waves and floods is not something new. If you look at a map of island archipelagos from over 100 years ago, you will see that many islands in it no longer exist (Fig. 2.6.8). This process is now advancing more quickly. Light beacons that were originally built at a safe distance from the cliff-edge are falling into the sea (Fig. 2.6.9), large human settlements are being engulfed and their inhabitants must be resettled, and roads need to be diverted.

Figure 2.6.7 Example of eroded seacoast



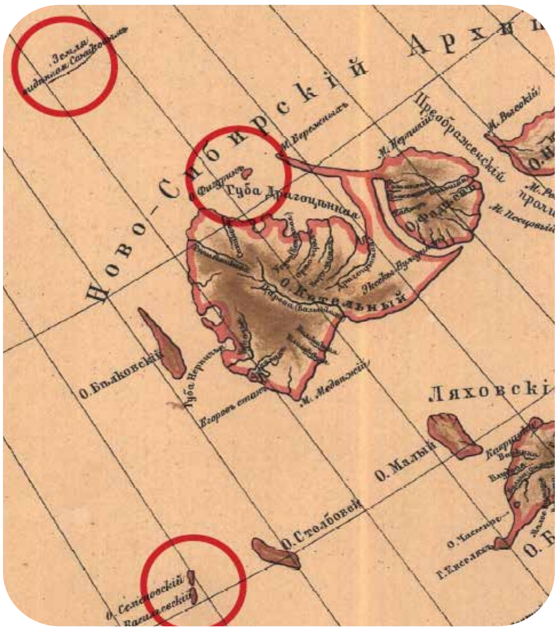


Figure 2.6.8

Coastal erosion in the Arctic. On this section of a map from 1890 showing the Laptev Sea and the New Siberian Islands the red circles highlight islands that no longer exist (they were swallowed up by sea storms)

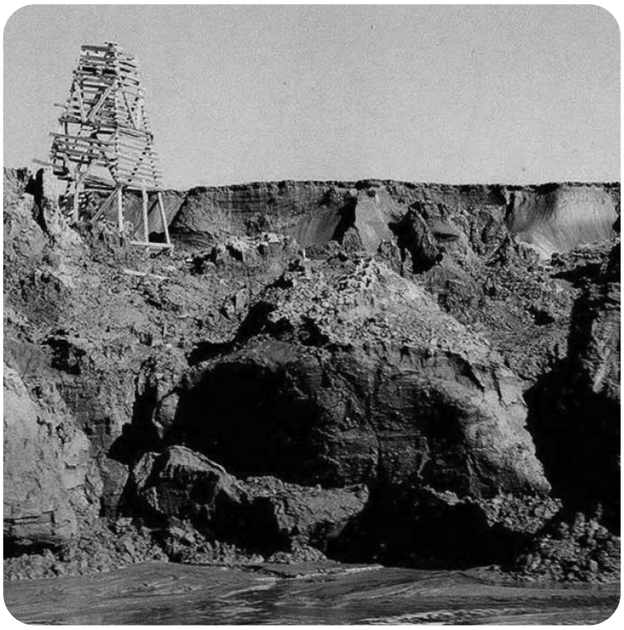


Figure 2.6.9

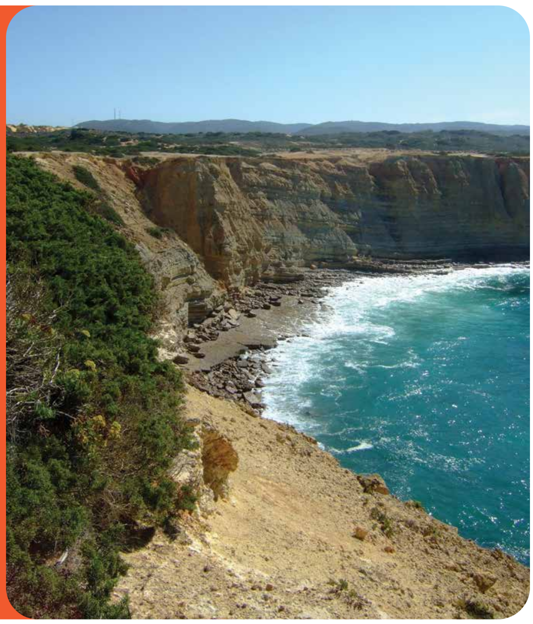
The Vankin coastal beacon (East Siberian Sea, Bolshoi-Lyakhovsky Island), which no longer exists

In Alaska, the entire village of Kivaluna, where 400 people lived on a narrow strip of land beside the Arctic Ocean, had to be abandoned and its inhabitants relocated away from the coastline. The cost of the operation was more than $200 million, although the village had no more than 70 dwellings.

Portugal's disappearing beaches

Environmentalists are concerned by the impact of erosion on the coastline of Portugal, which could soon deprive this European country of many of its beaches.

In some places along the coast the sea is swallowing several metres of land each year, and the situation is critical in the northern region of Espinho, where the shoreline has receded by up to 70 metres in the last few decades. This process is irreversible.



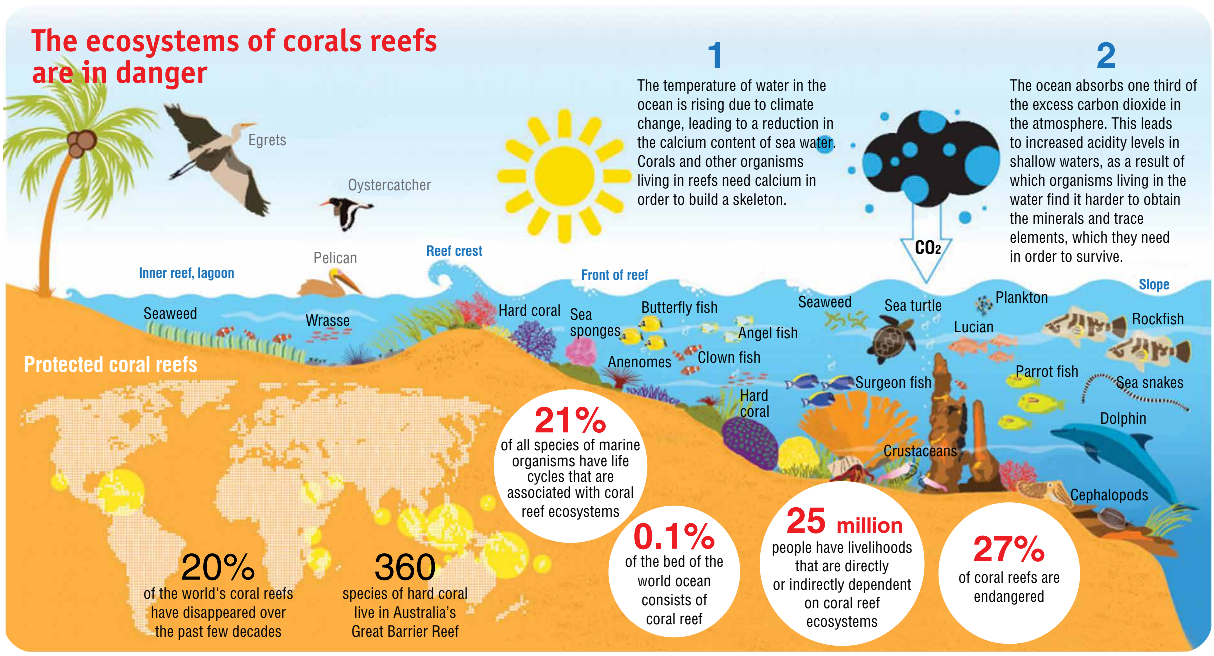
Risk to coastal ecosystems

The rise in sea levels not only affects people and the economy but also sea and land ecosystems along the coast.

The ecosystems of coastal lowlands are particularly vulnerable since they are typically only a few centimetres above the sea. Such lowlands are the habitat of many species of animals and plants and play a key role in the accumulation of nutrients. These ecosystems include salt marshes, which are flooded with sea water at high tide. Mangrove forests, commonly found in coastal lowlands with a humid tropical climate, are also threatened by rising sea levels.

Global warming poses a significant threat to coral reefs since the rise in water temperatures above a certain limit will lead to bleaching of the coral. Bleaching means that corals lose the symbiotic algae normally found in their tissues and become white because of stress. If bleaching is severe or prolonged, they can die. Such coral bleaching is already being observed in many places.

Figure 2.6.10 Coral reef ecosystems at risk



A long-term increase in the temperature of sea water may lead to major degradation of the whole coral reef ecosystem. Coral atolls, which serve as a habitat for a great number of living organ- isms, may be destroyed. Forecasts by the IPCC suggest that 18% of the world's coral reefs will be lost in the next three decades because of a variety of factors.

Climate change and fisheries

Scientists and fishermen are concerned by the increase in temperature and acidity of ocean water. As the concentration of CO_2 increases in the atmosphere, its absorption by the ocean is also increasing, which raises levels of acidity (pH). Changes in pH and water temperature have been enough to cause coral bleaching. By the middle of the present century, acidity may increase by 0.06–0.34 pH, which is 100 times faster than the rate of change in the last 20 million years. Many marine organisms will find it hard to adapt to the new conditions, with serious impacts on fish diversity and productivity.

Figure 2.6.11 **Forecast changes in acidity of the ocean's surface water by the end of the 21st century under the most favourable (left) and the least favourable (right) climate change scenarios change**

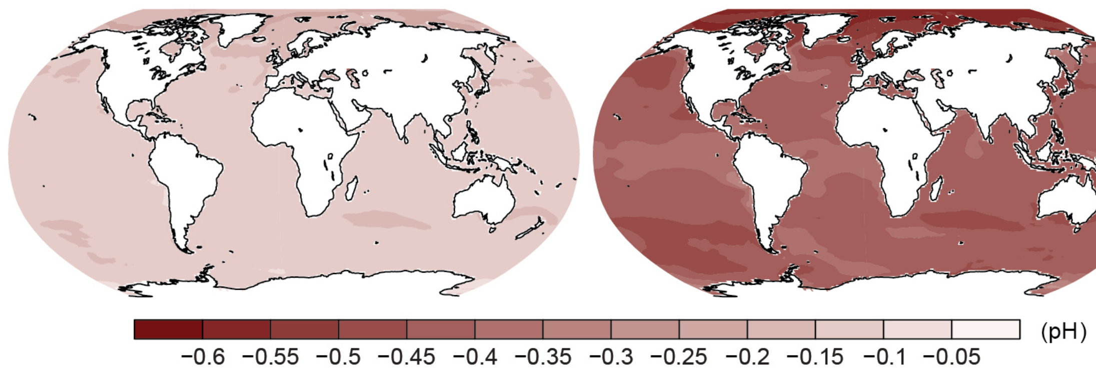
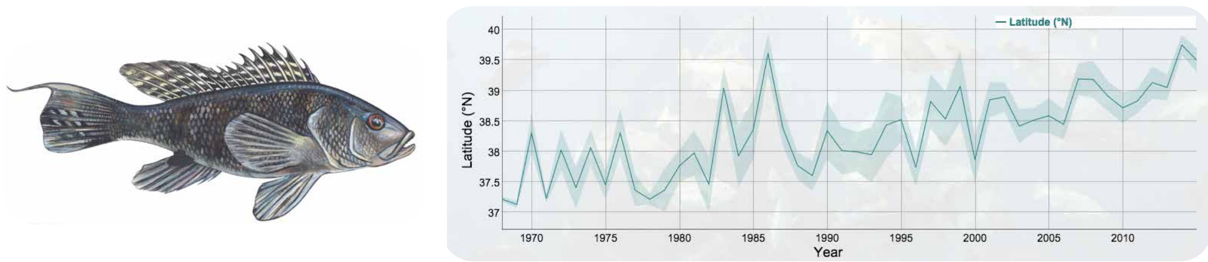


Figure 2.6.12 **Black sea bass is moving North as the oceans warm**



The National Oceanic and Atmospheric Administration (USA) and Rutgers University have developed the **OCEANADAPT webtool** to track changes in the movements of fish and invertebrates caused by changing climate and ocean conditions. The tool provides easy access to information about the changes in depth and latitude for nearly 650 marine species over the last 40–50 years. It is a useful resource for managers, fisherfolk, fishing communities, and scientists in developing timely adaptation strategies.

Changes in the properties of sea water are already leading to massive displacement of marine and freshwater fish species and the direction of their movements is not chaotic, but purposeful. Warm-water fish are moving to higher, cooler latitudes. This is not because of higher water temperature but a reduction in the amounts of phytoplankton, the staple diet of ocean fish, as the water temperature rises.

The numbers of cod off the coast of Greenland, and Japanese and Adriatic sardines increase during periods of climate warming and fall sharply during cold periods.

Many fish species are currently being fished at the limits of capacity to preserve their populations. Additional pressure from the need to adapt to climate change may push some species beyond their ability to reproduce in sufficient numbers to survive.

The loss of coastal habitats, including coral reefs and mangroves, is another major factor threatening fish populations.

The World Food Programme notes that fish represent more than 15% of the average protein intake for over 2.9 billion people. In small island states and some developing countries (Bangladesh, Cambodia, Equatorial Guinea, French Guiana, Gambia, Ghana, Indonesia, and Sierra Leone) fish provide more than 50% of animal protein intake. The populations of these countries are dependent on fisheries, so that any reduction in local catches represents a serious problem.

The rise in sea level is one of the changes to the global system resulting from climate change to which it is the most difficult to adapt. Strategies aimed at promoting adaptation are raising awareness of expected increases in the sea levels, improving early warning systems, and strengthening coastal defence and integrated coastal zone management.

QUESTIONS

1. Which country, Switzerland, or the Netherlands, will suffer the most if sea levels rise by more than half a metre?

2. Why are seacoasts being eroded rapidly?

3. What happened to lost islands?

4. Give examples of the impact of climate change on coastal ecosystems.

5. Why are some fish species moving to northerly latitudes?

6. What can be done to adapt to climate change in the coastal zones?

TASKS

1 Locate Tuvalu and the Republic of the Maldives on a physical map of the world. Find their height above sea level and explain why a rise in the level of the world ocean is so dangerous for them. Find other island nations and coastal countries which are also in danger of being fully or partially submerged by the sea in the next 50-100 years. Suggest ways of addressing the problem.

2 Show on a contour map how the appearance of the continent of South America would change if sea levels rose by 100m. Use coloured pencils to colour areas of land that would disappear under the sea. Think of geographical names for these areas. What will happen to the animals and plants there? Will they perish? Write down your suggestions in an exercise book.

3 Using the OCEANADAPT webtoo (http://oceanadapt.rutgers. edu/), find out how different fish species in the USA have changed their habitats in the past 40–50 years. Which species had to move the most? Why are these movements happening?

2.7 How climate change affects **mountain regions**

What are mountains?

"What are men to rocks and mountains?" exclaimed Elizabeth Bennett, the heroine of Jane Austen's *Pride and Prejudice*, excited about her forthcoming nature tour of pleasure in the summer. And it is true that mountains are one of the greatest creations of nature. What can compare with the breathtaking feeling when you stand on the top of a mountain, with only the blue sky above, and below you the world that looks so tiny, glimpsed under white clouds? At such moments you feel the beauty and power of nature, and at the same time its fragility.

Scientists define mountains as an elevated form of relief that rises above the surrounding plain. Unless they are volcanoes, mountains rarely stand alone, but usually form mountain ranges and ridges. Mountain ranges, in turn, come together to make mountainous countries or mountain systems.

Mountains may be high (above 3,000 m), of medium height (1,000–3,000 m) and low (up to 1,000 m). Low mountains usually have rounded summits and gentle slopes, but high mountains have steep slopes and angular peaks.

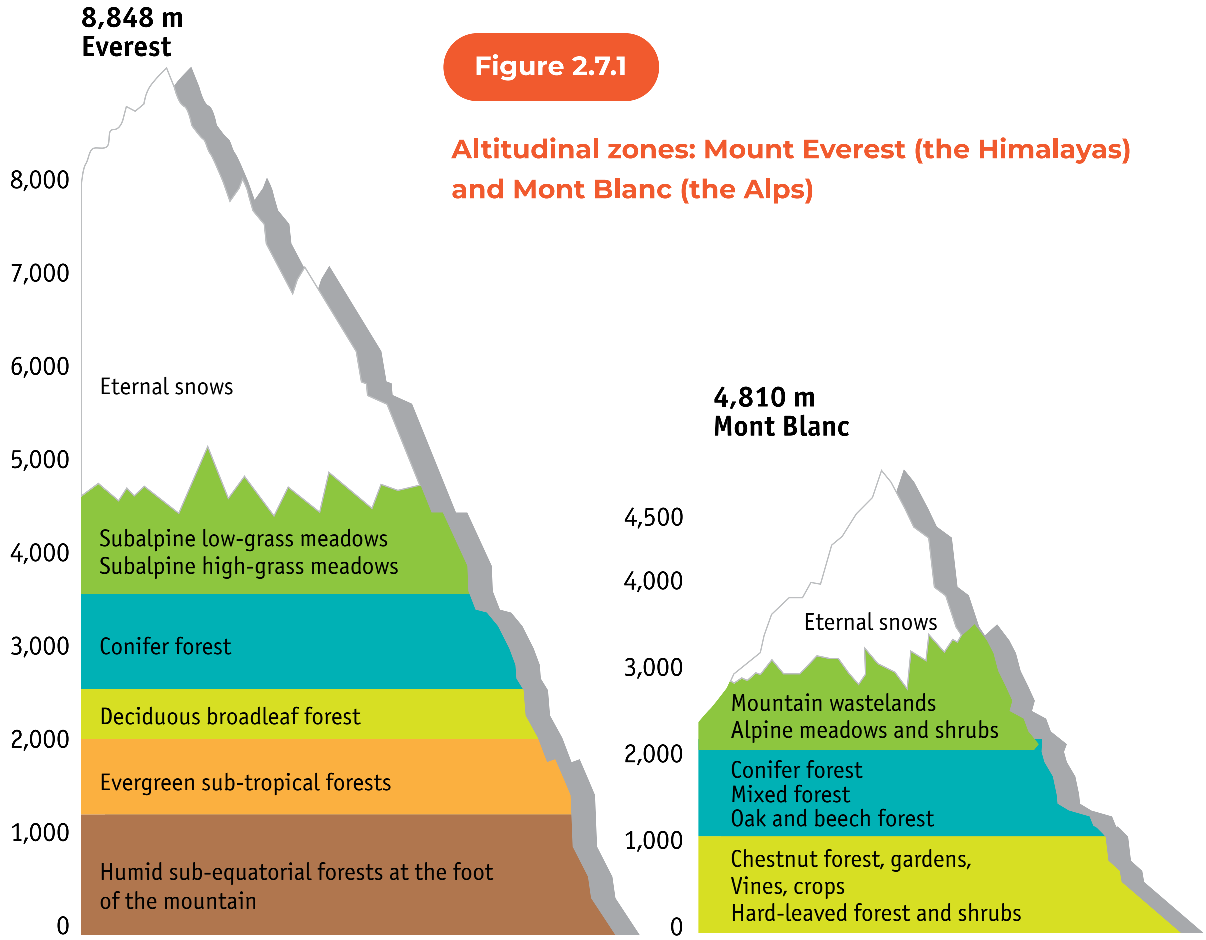
Mountains and climate

Mountains play a critical role in shaping the climate. They create a barrier to air masses, which cannot easily pass the high peaks. For this reason, different slopes of the same mountains often have different climate conditions, with more precipitation on one side than on the other. Average temperatures and landscapes may also differ significantly.

Mountains are also distinctive in that they bring together several different climates in a small area: the climate and landscapes change at different levels from the bottom to the top of the mountain. (Fig. 2.7.1). They are therefore called 'altitudinal zones' ('altitude' means 'height').

Figure 2.7.1

Altitudinal zones: Mount Everest (the Himalayas) and Mont Blanc (the Alps)



The world's highest mountains

The highest mountain range on the earth is the Himalayas, which in Sanskrit means dwelling of the snows. Ten of the world's 12 mountains that are over 8,000 metres high are located here, including the highest land point: Mount Everest, also known in local languages as Chomolungma or Sagarmatha. Mount Everest is 8,848 metres high.

The longest mountain range on land is the Andes. This gigantic South American mountain range extends along the entire Pacific coast of the continent.

Mount Aconcagua (6,960 m) in the Andes is the highest point in the western and southern hemispheres.

The largest mountain system in Europe is the Alps, which are shared between eight countries: Austria, Germany, Italy, Liechtenstein, Monaco, Slovenia, France, and Switzerland. Mont Blanc (4,807 m) in the Alps, on the border between France and Italy, is the highest point in Western Europe. The highest mountain on the European continent is the two-headed Elbrus Volcano (5,642 m) in the Greater Caucasus, which is also the highest peak of Russia.

North America has a system of mountain ranges, the highest of which are the Alaska Ridge and the Rocky Mountains. Mount McKinley (6,193 m) in Alaska is the highest peak in North America. Former US President Barack Obama announced on 31 August 2015 that Mount McKinley will be renamed Denali, as Alaskan natives call it. Africa's highest mountain is Mount Kilimanjaro (5,895 m). The highest mountain in Australia is Mount Kosciuszko (2,228 m).

Figure 2.7.2

N. Roerich. *Himalayas.* Everest. 1938

Figure 2.7.3

The two-headed Elbrus volcano (5,642m), the highest peak in Europe

You've probably wondered why mountain peaks are often covered with snow, even in tropical latitudes. The first mountain climbers quickly found that the higher they went, the lower the temperature became and the harder it was to breathe. Air is heated by the sun and by the earth's surface. Once it has become warm, it rises and expands, losing its heat. So, with increasing altitude, the air pressure, and its temperature gradually decrease.

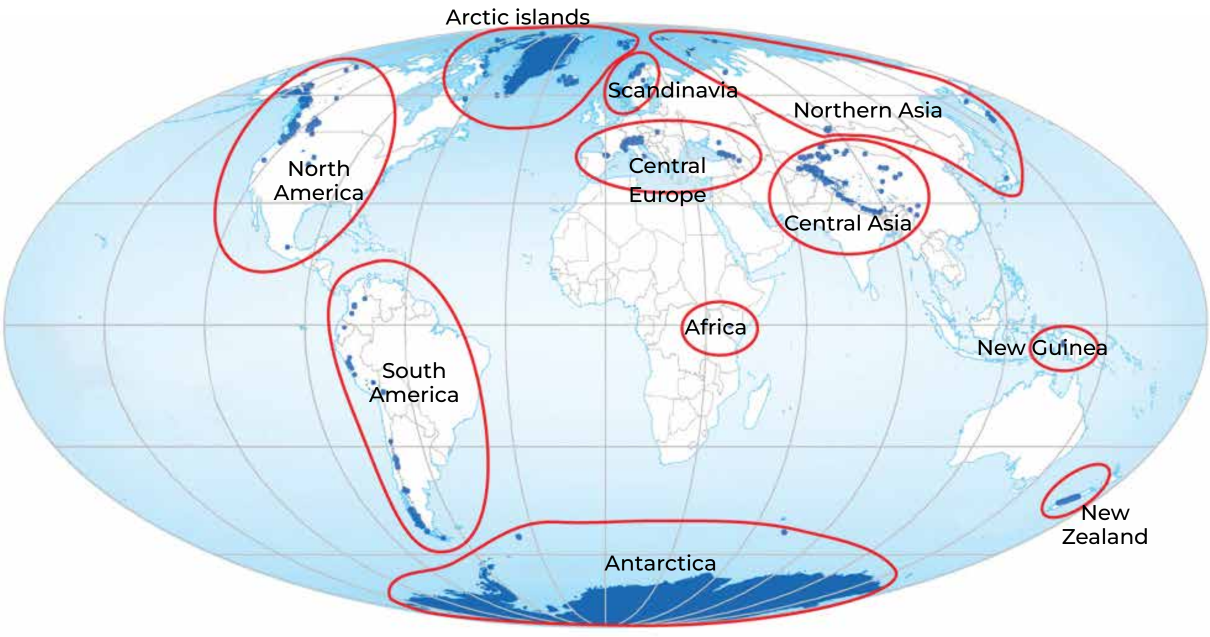
With elevation, temperature falls on average by 6°C per kilometre from the earth's surface. So, if the temperature at the foot of a 4,000-metre mountain is +24°C, the temperature at the top will be around 0°C. That is why, even though the average air temperature in the tropics never drops below zero, there can still be snow at high altitude on mountains.

Mountains affect the climate, but they are also highly dependent on it. Mountain regions are among the first to respond to changes in climate conditions. The main 'indicator' of climate change in the mountains are glaciers, which shrink or grow depending on whether the climate is becoming warmer or colder.

Melting beauty

Glaciers are formed in mountain ranges when the build-up of snow in the upper parts of the mountains turns to ice. The formation of a glacier requires a cold and wet climate, in which more snow falls during the year than has time to melt. As soon as temperatures rise and precipitation declines, the glacier ceases to grow and starts to melt.

Figure 2.7.4 **Glacial regions of the Earth**



Mountain glaciers around the world began to melt (to 'retreat') about 15,000 years ago, when the last period of glaciation gave way to a new period of warmer climate. This melting process was accompanied by short periods when glaciers advanced once again. We know from history that in the 5th–7th centuries A.D., many mountain passes now occupied by glaciers were used as caravan routes. When the climate grew colder, glaciers began to grow, and by the 17th–18th centuries these passes were no longer open.

One example is the famous St. Gotthard Pass in the Alps. As the poet Frederick Schiller described it in 1799, "To the solemn abyss leads the terrible path / The life and death winding dizzy between," crossing the snow-covered pass was wildly dangerous and possible only during a couple of summer months.

Figure 2.7.5 W. Rothe. *Crossing St. Gotthard Pass*, 1790

However, over the past 70 years, glaciers around the world have been retreating particularly fast (Fig. 2.7.6). Scientists are sounding the alarm: the rapid melting of mountain glaciers we are seeing today does not coincide with a natural cycle. A reduction in the volume of mountain ice may lead to catastrophic consequences for the environment and the economy of mountain regions, as well as their surrounding plains, which are home to as many as one in six of the world's population.

Figure 2.7.6

Change in the mass of mountain glaciers around the world, 1950–2022, measured in units of meter water equivalent (m. w. e.)

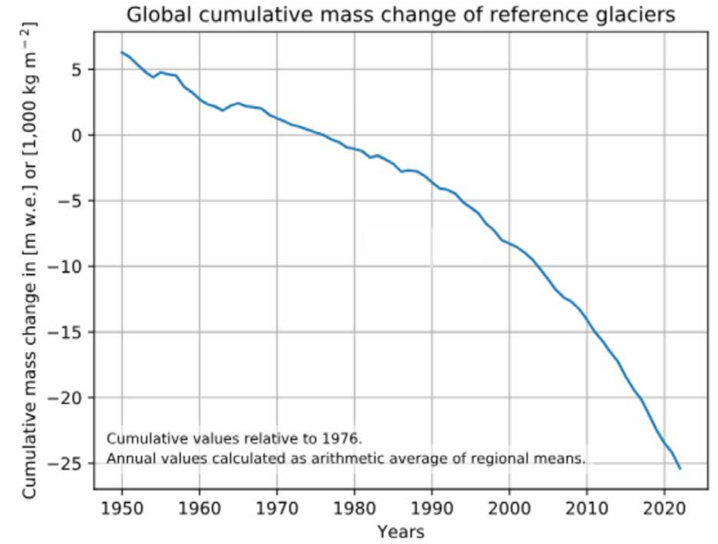


Figure 2.7.7

This is how scientists study glaciers

Mountain glaciers are retreating

Glaciers in the Himalayas are retreating by an average of 10–15 metres per year. The Gangotri Glacier, which is the source of the River Ganges, is melting particularly fast, retreating by 30 metres each year. Gangotri is one of the main sources of water for the 500 million people who live along the River Ganges.

Glaciers in Peru are also retreating rapidly. According to the most conservative estimates, their area has fallen by a third over the past 30 years.

The African volcano, Kilimanjaro, has suffered perhaps the worst of all: its famous ice cap, immortalized in Ernest Hemingway's novel, *The Snows of Kilimanjaro*, has almost entirely disappeared.

Figure 2.7.8

The Gangotri Glacier

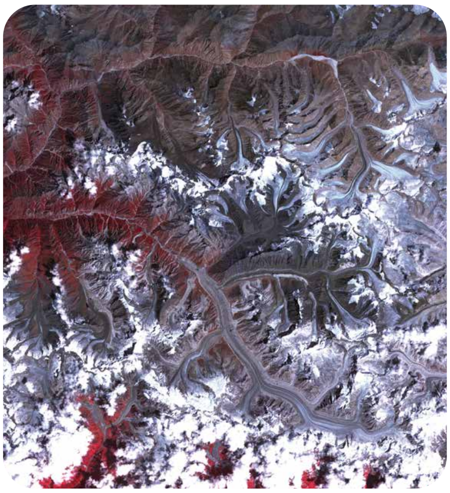


Figure 2.7.9

The cap of ice and snow of Mount Kilimanjaro has almost disappeared

Glaciers in the Alps are melting faster than ever. According to research conducted in 2023 by the scientific group Glacier Monitoring Switzerland (GLAMOS), Switzerland's glaciers lost as much ice in two years as in the three decades before 1990: in just two hot summers in 2022 and 2023, the Alpine glaciers have lost the same volume of snow as that between 1960 and 1990. Scientists concluded that climate breakdown caused by the burning of fossil fuels is the cause of unusually hot summers and winters with very low snow volume, which have accelerated the melting of the glaciers. The European Environment Agency expects that 75% of Alpine glaciers will have melted by 2050.

In the mid-19th century, the Glacier National Park in the Rocky Mountains, on the border between USA and Canada, was home to as many as 150 glaciers. By the start of the 21st century, only 25 remained, and scientists predict that they will disappear in the coming decades, so visitors who want to see what the park was originally famous for should hurry up!

Figure 2.7.10 **Glacier National Park in August 2013**

The volume of glaciers in New Zealand decreased by 11% from 1975 to 2005. The most rapidly melting glaciers in that island country are the Tasman, Classen, Mueller and Maud glaciers.

Figure 2.7.11

The Greater Azau Glacier in the Caucasus. The photograph displayed by the woman is from 1956. Behind her you can see what remained of the glacier in 2007

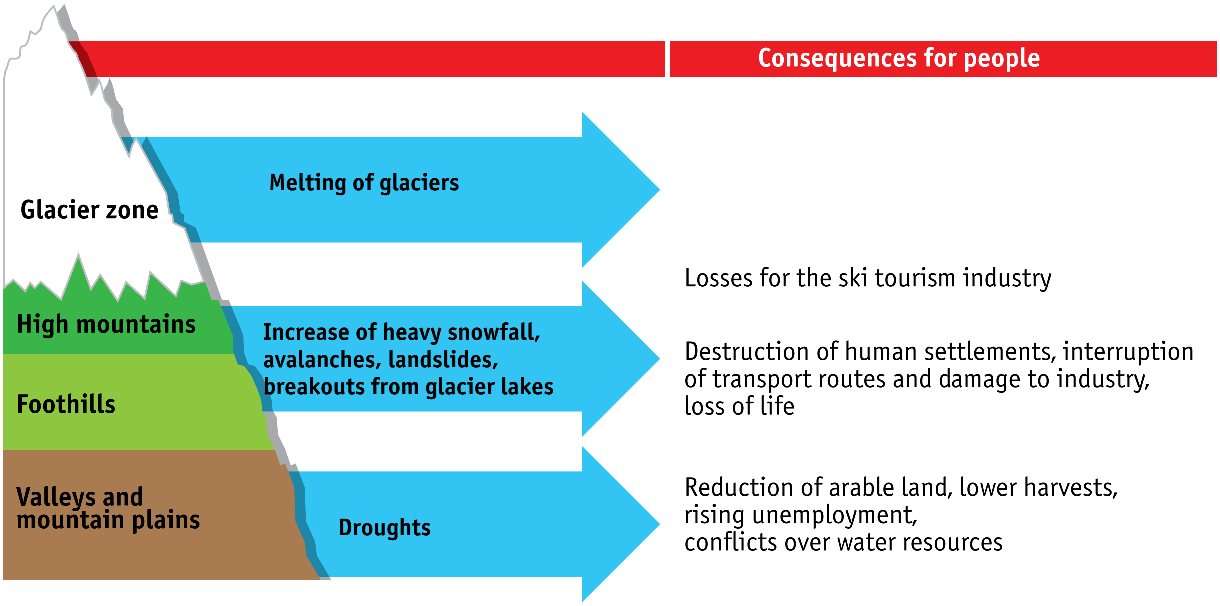
The Azau glacier in the Caucasus has undergone significant changes. At the end of the 19th century the melting process caused it to divide into two parts, called the Lesser and Greater Azau. Today the Greater Azau is no longer great. From 1957 to 1976, the glacier retreated by 360 metres, and then by a further 260 metres from 1980 to 1992. The Lesser Azau retreats by about 16 metres each year.

The number of glaciers in the Altai Mountains in Eastern Russia decreased by 7.5% from 1952 to 1998, and those which remain have retreated by 100–120 metres from their position in the mid-19th century. The Sofia glacier, being observed by experts from Altai State University, has retreated by 1.5–2 km in the last 150 years. This glacier is also 'rising' at a rate of 20–30 metres each year.

How climate change affects people who live in the mountains

Living in the mountains is not easy. The high altitude, difficult terrain and frequently changing weather make it much harder to grow food and manage cattle here than on the plains.

Figure 2.7.12 The impact of climate change on human life in the mountains



Since ancient times, people have settled in narrow mountain valleys, separated from one another by high mountain ranges with steep slopes, which often made contact between the neighbouring valleys (and populations) difficult. Even now, people living in mountainous regions often have their own unique customs, culture, and ways of making a living. The way of life of mountain people and their principal livelihoods – agriculture and tourism – are directly dependent on the climate. Even small changes in climate can affect their wellbeing.

Tourism going downhill

The example of the Alps shows how climate change is affecting tourist industry in mountain areas. Ski tourism provides up to 20% of the income of Alpine countries (Fig. 2.7.13). For the 13 million people living in the Alps in Austria, Germany, Switzerland and France, the lack of snow is an economic catastrophe: two thirds of all tourists who come here do so for skiing and snowboarding.

Forecasts give serious cause for concern: by 2030 there will be almost no snowfall in the Alps below 1,000m altitude, which will put many popular ski resorts out of business. Half of all the ski resorts in Austria are at altitudes up to 1,300 metres and will be forced to close due to lack of snow. The pessimistic predictions are already starting to come true: in the winter of 2006–2007, as many as 60 of the total 660 alpine ski resorts remained closed, and many others could only operate by using artificial snow, which greatly increased their already high costs. The result has been a fall in demand for holidays in the Alps.

How can mountain regions cope without snow? The sport and leisure industry is adapting as best it can, working to develop other types of tourism and recreation, which are less dependent on snow. Areas that were used for skiing are being converted into leisure parks and all-year-round health resorts. A time may come when people will go to the Alps, not for winter sports, but to enjoy walks along mountain lakes, savour the local food and breathe the fresh mountain air.

Figure 2.7.13

Tourist industry makes a large share of the income of mountain regions

Trift Lake in the Swiss canton of Bern is an interesting instance of how global warming is affecting the Alps. In the 1990s, a nearby glacier began to shrink rapidly, the melt water formed a small lake and more of the valley became free of ice. Previously, people could walk from one mountain peak to another across the glacier. The local authorities decided to build a suspension bridge for walkers before the glacier completely melted, and the bridge quickly became a major attraction, drawing visitors from all over the world.

Figure 2.7.14

Bridge over Trift Lake, Switzerland

The Pastoruri Glacier in Peru is retreating

Until recently, tourists and professional climbers used to flock to the Pastoruri Glacier, which towers over the Andes in Peru. But the glacier has shrunk by more than a quarter in the last 35 years and scientists predict that it may disappear altogether in the next few decades. A breathtaking landscape of snow and ice has given way to black cliffs. Local authorities have prohibited climbing because the melting glacier has made the rocks unstable.

The number of tourists who come to admire the Pastoruri Glacier has fallen three times since the beginning of the 1990s, with major impacts on tourism in Peru and the income of residents. But Peruvian entrepreneurs have not despaired: they now show off the remains of the glacier as a striking example of the results of climate change, and the region has been successful in attracting increasing numbers of environmentalists and curious tourists.

But, of course, restoring the glacier itself is a much harder task than restoring the fortunes of local business.

Figure 2.7.15 **Retreat of the Pastoruri Glacier in the Peruvian Andes**

Natural disasters in the mountains

The decline of the tourist business is not the deadliest threat to mountain people from global warming. They also must fear natural disasters – avalanches, landslides, and floods – which have become ever more frequent in the mountains as the climate changes, posing a threat to human life and causing huge damage to the local economy.

When a glacier retreats it produces melt water, which accumulates in a mountain valley to form a glacial lake. As the quantity of water increases, the lake may overflow, causing a flood. Scientists believe that 20 glacial lakes in Nepal and 24 in Bhutan pose a serious threat to people living further down the valley. If these lakes breach their banks, and the water gushes into the valley, many people are in danger of losing their lives and/or their homes. Several such floods have already occurred in recent years in the valleys of the Thimphu, Paro and Punakha-Vangdu rivers in Bhutan.

The danger to the local population can be reduced by digging protective channels and dams before such flooding occurs.

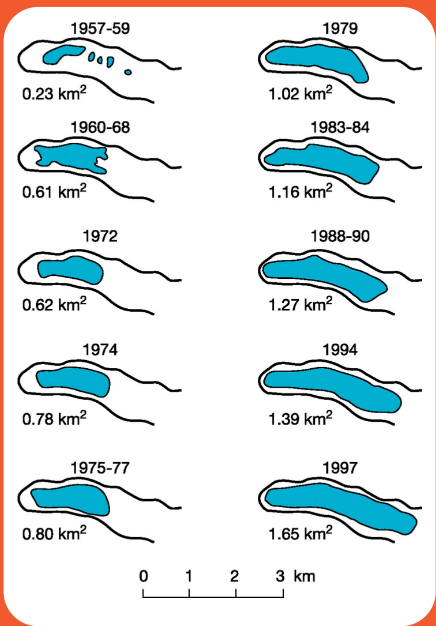
The **Tsho Rolpa Lake** in Nepal, which was formed by water from melting glaciers, has expanded seven-fold over the past 50 years. Studies show that more than 20 glacial lakes in Nepal and 24 in Bhutan may soon overflow, which could lead to catastrophic consequences for the people and economies of these countries unless appropriate precautions are taken.

Figure 2.7.16

Glacial lakes in the Himalayas

Figure 2.7.17

Lake Tsho Rolpa has grown by seven times in the past 50 years



An **avalanche** is a huge mass of snow that falls or slides off mountain slopes. Avalanches can have disastrous consequences. In February 1999, an avalanche weighing 170,000 tonnes destroyed the village of Galtur in Austria and claimed the lives of 30 people. In March 2012, a series of avalanches in Afghanistan destroyed homes, killing more than 100 people. More recently, in January 2023, an avalanche struck a road in Nyingchi, China, and killed 28 people and injured 53 others.

A landslide is a tremendously powerful mass of mud and rocks, which suddenly slides down mountain river valleys. Landslides are usually caused by heavy rains or rapid snow melt. They can also be caused by the breakout of water from glacial lakes. Landslides, like avalanches, can cause massive destruction.

Reduction of freshwater stocks

The future reduction of freshwater stocks, both in mountain regions and in adjacent plains, presents a serious threat. Glaciers are one of the main sources of fresh water since they are the source of many rivers. Melting ice will lead to water shortages in the regions around mountains, making conditions much worse for agriculture, mining, and electric power generation. A shortage of fresh water in areas near mountains is already leading to serious political conflicts in some parts of the world. Scientists note that climate change impacts on the mountains, such as hydrological changes resulting from the retreat of glaciers or some ecosystem changes, cannot be reduced through adaptation measures.

Mountains have always been associated with danger, and climate change may add to the risks. Rise of temperatures, changes in the amount of precipitation, the melting of mountain glaciers, and the more frequent occurrence of unpredictable natural disasters could lead to catastrophic consequences for the environment, the people and the economy of mountain regions and surrounding areas.

QUESTIONS

1. How high has a mountain climber climbed if he is at a level where the temperature is -9°C, when the temperature at the foot of the mountain is +18°C?

2. Will snow remain at the top of a mountain 5200 m high, if the air temperature at its foot is +30°C on the hottest day of summer?

3. Why are mountain glaciers often called indicators of climate change? What happens to them when the air temperature changes?

4. Why is there often a great deal of ethnic diversity in mountain regions?

5. What are the main livelihoods of people living in mountain regions? How are they affected by climate change?

6. What can be done to preserve the main livelihoods of people living in the mountain regions and adapt to consequences of climate change?

TASKS

1 Mark the highest peaks on each continent on a contour map of the world. Which mountain systems are they a part of? In which countries are they located?

2 The beauty and the inaccessibility of mountains have always inspired the greatest poets, writers, artists, and composers. Name some famous works of literature or art that show various mountain ranges or peaks. Choose any work that you particularly like and explain what the author would have to change if they had lived in an era of global climate change. How could they do it?

3

Game
The players divide into two teams.

Team № 1 live in High Village, which is in the Rapid River Mountain valley. In recent years the melting of glaciers in the high mountains has caused the Rapid River to flood its banks on several occasions, causing problems for residents. So, they want to build a dam on the river to protect themselves from floods and at the same time produce electricity and create new jobs. The mountain people are not rich, they have no money for the construction of the dam and live mainly on what they can grow and the animals they keep. In recent years, due to rising temperatures the people of High Village have begun to grow flowers and exotic fruits.

Team № 2 live in the village of Cowgrazing, which is on the plain near the mountains, downstream on the Rapid River. The village is prosperous, its people are farmers and use water from the river for irrigation and for drinking. The people of Cowgrazing like exotic food, entertainment, and travel. The local budget has plenty of money to finance new construction projects.

Members of the teams need to discuss the following questions (the teacher or one of the students can play the role of Minister for Regional Development, who will manage the negotiations):

1) What will be the consequences for the village of Cowgrazing if the people of High Village build a dam without consulting them?

2) On what terms can the village of Cowgrazing agree to the dam and provide money for its construction?

3) Can the people of High Village find ways to protect themselves from the consequences of climate change without building a dam?

4) What new projects and types of business can the people of High Village and Cowgrazing work on together?

2.8 How climate change affects the Arctic regions

The Arctic is the Earth's northern polar region, which includes the Arctic Ocean and its seas, the northern parts of the Pacific and Atlantic Oceans, the Canadian Arctic Archipelago, Greenland, Svalbard Island, Franz-Josef Land, Novaya Zemlya, Severnaya Zemlya, the New Siberian Islands and Wrangel Island, as well as the northern coasts of Eurasia and North America.

There are no hard and fast boundaries to the Arctic region. The most common definition of its southern boundary is the Arctic Circle at northern latitude of 66 degrees and 33 minutes. This makes the total area of the Arctic 21 million km^2 (Fig. 2.8.1).

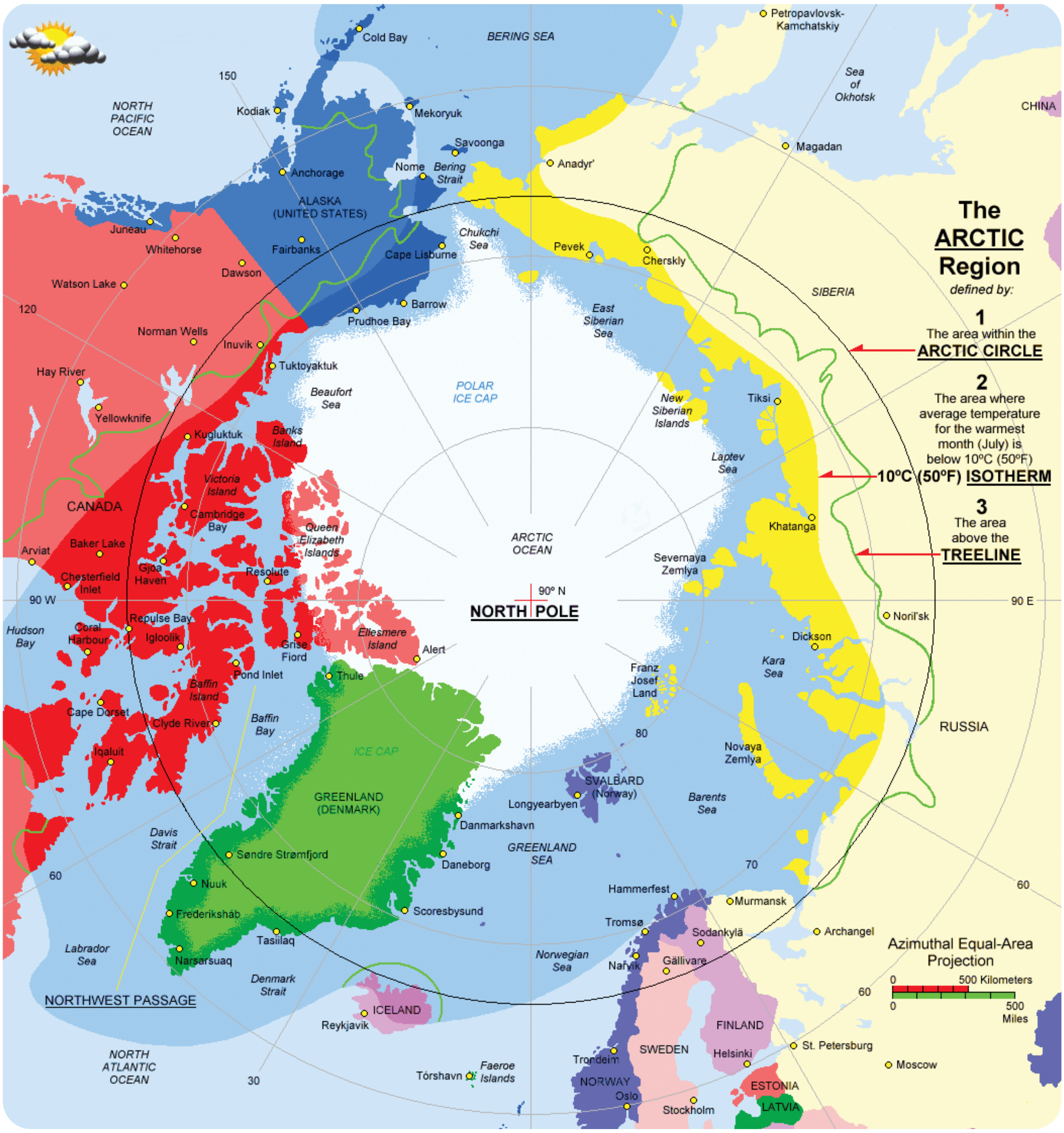
A second definition of the Arctic region is the July isotherm – an imaginary line where temperatures in the warmest month of the year are not greater than 10°C. The tree line roughly correlates to the July isotherm and constitutes the third definition of the Arctic. The tree line marks the transition from the forests zone to the shrubs and grasses of the tundra. Russia, the United States (Alaska), Canada, Norway, Sweden, Finland, Iceland, and Denmark (Greenland) all have Arctic territories.

The Arctic is getting warmer faster than the rest of the world

Climate change in the Arctic is much more pronounced than on average in the world. Temperatures along the Arctic coast have risen already by 2-3°C in recent decades.

But the most noticeable effect of climate change on the Arctic has been an increase in fluctuations of climate and weather. In temperate climates, sudden changes of temperature are usually not greater than 10°C: it may be quite warm today, but tomorrow the temperature falls by 10°C, and then it rises again by 10°C a week later. But in the Arctic the temperature can change suddenly by as much as 20°C, and summer temperatures in one Arctic region can be 5°C warmer than they were in the mid-20th century, while in a neighbouring region they are 5°C cooler.

Figure 2.8.1 The Arctic and definition of its boundaries



It might seem that warmth in the Arctic is a good thing, but that is not always true! Which is better: a temperature of -35°C with clear, windless weather, or -20°C with a blizzard? Of course, it's better to be colder, but without the blizzard, particularly since the Arctic is used to such temperatures. The issue is not temperature: whatever happens, temperatures in the Arctic will never be high enough for people and animals there to get overheated.

There is a concept in meteorology called the **wind chill index**, which reflects how cold people feel from the combined effect of low temperature and wind. For example, at air temperature of -10°C and wind speed of 30 km/h the wind chill index will be -20°C, which is to say that a person will feel and react to these conditions as if the air temperature was -20°C.

Various climate parameters affect the lives of people and ecosystems in the Arctic: the power of the wind (blizzards and storms), reduction of the extent of sea and river ice, severe coastal erosion, and the melting of permafrost. Changes to these parameters are not just a consequence of rising temperatures – the parameters themselves are active forces helping to drive temperatures upwards. Scientists call such inverse effects 'feedbacks'. There are at least two of them:

1. Higher air temperatures cause ice fields to melt and break up, leaving large expanses of open water between ice floes. The dark surface of the water, unlike ice, does not reflect but absorbs solar radiation, so the water grows warmer, more ice melts and the process is accelerated.

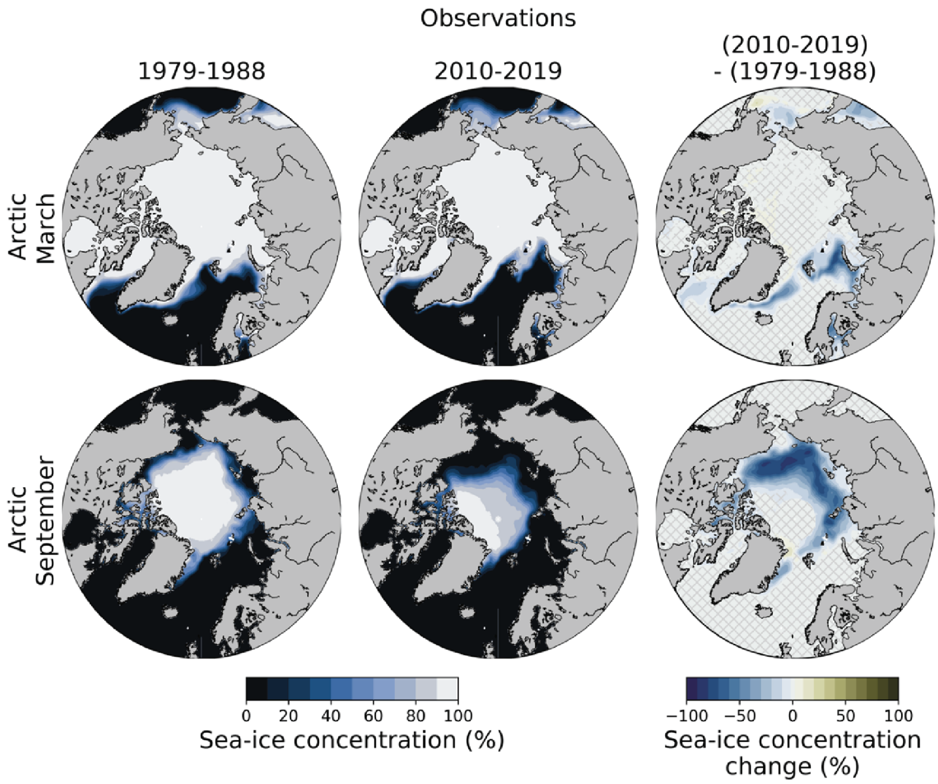
2. More open water means more evaporation of moisture and more clouds. Remember, nights are relatively warm when the sky is cloudy, because clouds trap heat, and it is much colder on a clear night. Similarly in the Arctic, when there is a lot of open water and clouds, the temperature is higher, especially at night, which also makes ice melt faster.

The Arctic economy has two polar types of activities. On the one hand, there are the traditional activities of the indigenous population, such as hunting, fishing, reindeer herding. On the other is large-scale production of oil and natural gas, iron, zinc, gold, diamonds, fish, and timber for an international market. The largest economies in the Arctic belong to Russia and Alaska (USA) mainly because of their mining and petroleum sectors. Regions that are still heavily dominated by more traditional small-scale activities, especially in Greenland and Northern Canada, have a much lower economic output.

The disappearing ice of the Arctic

Scientists have been monitoring ice in the Arctic since 1979 by means of satellites. Satellite data show that the amount of ice in the Arctic has declined dramatically (Fig. 2.8.2). Maps of Arctic sea-ice show satellite-retrieved mean sea ice concentration during the decades 1979–1988 and 2010–2019, as well as the absolute change in sea ice concentration between these two decades. Over the past 40 years, the sea-ice concentration in the Arctic Ocean and its seas has decreased by more than 20%.

Figure 2.8.2 Maps of Arctic Sea ice concentration for March and September, which are usually the months of maximum and minimum sea ice area, respectively



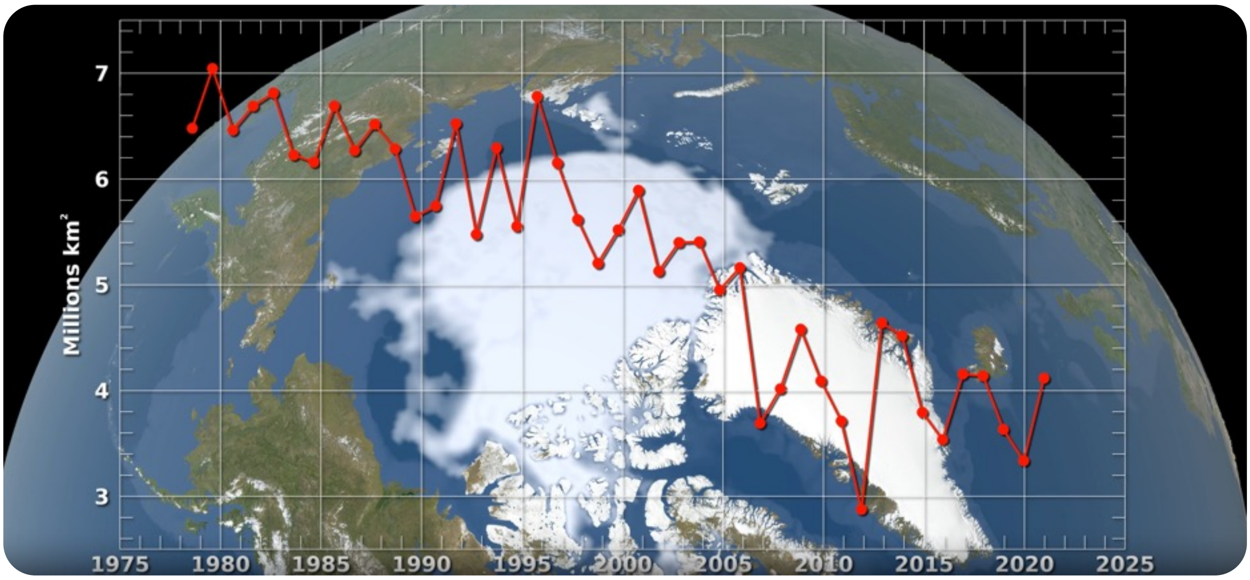
The area of ice is usually measured by its maximum and minimum extent for the year, normally at the end of March and September. The shrinkage in September 2012 set an absolute record: the area of sea ice shrank to 3.41 million km^2 (Fig. 2.8.2 and 2.8.3).

Of course, ice still covers the whole of the Arctic in winter. Even gigantic warming of 15–20°C would not lift winter temperatures in the polar regions above zero. But it would greatly thin out the ice. This effect is already clearly visible.

Scientists note that a reduction in the extent and thickness of sea ice could offer new opportunities for greater use of the northern sea route for transporting goods between Europe and Asia, and vice versa. Transit via the seas of the Arctic Ocean is much shorter than the traditional route through the Suez Canal and can significantly reduce the cost of shipping.

Ships have the best chance of traversing the northern sea route in September, when the area of ice is at its lowest extent. But even when ice cover is at its lowest (Fig. 2.8.2), there is no guarantee that all the straits will be open. This is particularly true of the Vilkitsky Strait between Taimyr and Severnaya Zemlya, which represents a bottleneck for the entire Northern Sea Route. This strait remained ice-bound even in 2007. On the other hand, there are occasions when the overall ice cover is much greater, but straits are passable. In sum, it is too early at present to speak confidently of ice-free navigation along the Arctic coast of Russia. Climate models suggest that the Arctic will become completely free of ice in the summer only from about 2050.

Figure 2.8.3 Extent of Arctic Sea ice (annual minimum area) between 1978 and 2022



It is important to remember that the melting of ice in the Arctic leads to the formation of icebergs, which pose serious dangers to ships and oil platforms positioned on the continental shelf in the open sea. In the future, shipping and oil companies will need to ensure proactive protection from icebergs avoiding collisions and accidents.

Threats to the animals in the Arctic

The melting of ice in polar regions has major impacts on marine animals, including the 'king' of the Arctic, the polar bear. He does not need ice, but his main prey are seals, which are always found at the ice edge.

Due to global warming the ice edge now retreats northwards very quickly in the Arctic spring – so quickly that polar bears do not have time to react and are cut off from the seals by vast expanses of ice-free water (Fig. 2.8.4). A bear can swim dozens of kilometres but not hundreds of kilometres, and the swimming ability of cubs is very limited. As a result, many bears are stranded on the coast. They grow hungry and may enter villages to seek food at garbage dumps, which can be very dangerous, both for the animals and for people. There are a few ways of addressing this problem.

Figure 2.8.4

This bear, left stranded on the coast, more than 100 km from the edge of the ice pack, is very unhappy about climate change

First, people should have means of deterring bears, such as guns that fire rubber bullets. Second, villages should be kept clear of old food waste, which should be left at least one to two kilometres away from the village, so that the bears go there, away from people. Third, men who are specially trained, armed and equipped (with radios and satellite phones) should keep a watch on bears to prevent bear attacks and poaching.

Although having to do without their favourite meal of seal, bears can find enough food to eat on the seacoast (dead birds, eggs and small animals). They can also hunt walruses, although a polar bear will not tackle an adult walrus: a weak, wounded animal or walrus calves are better prey. Bears will sometimes break into a walrus rookery, causing a panic in which the walruses press together, and calves are crushed by the large males, leaving food for the bears. Such bear tactics are particularly successful if walruses have made their home not on a flat beach, but on a slope or on cliff ledges: as the large animals fall downwards. They may crush younger animals beneath them.

Walruses are increasingly forced to choose such unsuitable places for their colonies, also due to the lack of ice. Walruses not only need ice floes, on which they can rest during migration without losing their strength. They also need shore ice. Where there once were large quantities of thick, coastal ice, part of it lying on the beach as a crust, there is now much less of it, and storms are rapidly eroding suitable sites for walrus colonies. The animals are therefore forced to choose other places, where they are threatened not only by bears, but also by people.

There have been instances when thousands of walruses have appeared in new places (Fig. 2.8.5), including locations near aerodromes. The sound of an approaching aircraft caused a panic stampede, in which dozens of animals were killed. To prevent this from recurring, people at the aerodrome made noise on purpose before the arrival of planes, so that the walruses would take to sea. But such solutions require careful monitoring of the movement of walrus populations, with the deployment of people and equipment.

Figure 2.8.5 A record number of some 35,000 walruses gathered on shore near Point Lay, Alaska in September 2014. They were looking for a place to rest after a long swim in the absence of sea ice

The Barents and Kara seas are the habitat of the Atlantic walrus, which is listed in the Red Book. There are only a few rookeries of these animals, some of which are in remote areas of Franz Josef Land, but others are in relatively accessible places, along transport routes and in locations where there are plans to build oil and gas platforms. It will be essential to carefully monitor and identify problems early on, to prevent the disappearance of walruses in this part of the Arctic.

The survival of harp seals in the White Sea presents another challenge. Unlike bears and walruses, seals cannot live on the coast, where they fall easy prey to wolves, dogs, and other predators. For a long time, the harp seal was hunted by the human population of the Arctic coast, and the white fluffy fur of young cubs was specially prized. Hunting is now prohibited. Many seals also perished due to the passage of ships through areas where they lived. Ship captains are now required to avoid places where seals congregate.

Seals in the White Sea were previously hunted for the fur of seal pups. Shipping routes that cut through places where the animals congregated also caused problems. Nowadays the seals face another problem: the depletion of strong ice cover in the White Sea due to global warming, making it harder for them to raise their baby seals.

Seals have another problem caused by climate warming: the fur of seal pups is very warm, but not waterproof, so falling into water or even into puddles formed on the ice as it melts can be fatal for them: they freeze, fall ill and often die. In the future, if quantities of ice are much reduced, it may be necessary to find a protected island where young pups can grow up in safety.

Climate change is also affecting reindeer. Poor ice cover on rivers means that herders find it harder to guide the herds to the right places at the beginning of the winter. Reindeer can swim across a river or walk across sturdy ice. But they cannot cross a river with weak ice. The disappearance of ice on rivers earlier in the year and melting of the tundra create obstacles to reindeer migration and often leads to the death of many animals.

We cannot stop climate change easily and quickly, so it is vital to address such problems by removing other man-made barriers – for example, by making sure that gas pipelines do not impede the migration of reindeer. At present pipelines in the permafrost zones are built above the ground on special supports, and deer can neither crawl under the pipes nor jump over them. Special overhead sections are needed so that the animals can pass under the pipes.

Melting of the permafrost

People have lived in the Arctic permafrost zone for many thousands of years, but they were indigenous peoples (Chukchi, Nenets, Yakuts, Evenks, Aleut, Yupik, and Inuit) who did not build houses, and their existence did not damage the frozen ground in the Arctic permafrost zone. When Russians first came to the Arctic and found that the ground freezes to a depth of several metres and that only the top layer melts in the summer, they were much surprised. Leaders of the colonists wrote that the land was frozen, so that it was impossible to sow wheat. In the Russian city Yakutsk, a well was dug to find out how deep the frozen soil went: in 1686, it was dug to a depth of 30 metres, but did not reach the bottom of the permafrost. Some 150 years later work on the well resumed and it was dug to a depth of 116 metres, but the ground at that depth was still frozen.

Figure 2.8.6 Melting permafrost, Svalbard, Norway

The nature of permafrost was only understood at the end of the 19th century, when it was found that permafrost went as deep as 1,500 m in some places, but the frozen layer, with temperature between -2°C and -7°C, was usually 100 m thick.

In places where there is no permafrost, the sub-soil temperature is always a few degrees above zero, so that water pipes can be safely laid and streams and small rivers be channelled through pipes and tunnels, as may be necessary in towns and cities. The top layer of soil thaws in the summer, but the frozen layers remain in place from a depth of 10 cm in the north to 1m on the southern permafrost boundary.

Figure 2.8.7

A vertical section of permafrost with ice layers

Building on permafrost ground is difficult because frozen ground cannot be dug but must be laboriously broken up or melted. It is possible to drill, saw, and even explode the permafrost, but that is expensive and requires special equipment. The permafrost contains large quantities of ice, sometimes whole layers of it (Fig. 2.8.7).

So, when the top of the permafrost melts in the summer, it forms a very weak 'semi-liquid' layer incapable of supporting buildings, bridge supports or power lines. Such constructions must rest on stilts, which go deep into frozen ground, reaching levels at which the ice never melts.

Further problems arise from the fact that the summer thaw is very uneven. The surface terrain is not flat, and the nature of the ground may alter just a few metres to the left or right. It might happen that more water accumulates in a certain place during the warm season and cannot escape underground due to the permafrost. When the winter comes, the trapped water freezes into ice inclusions (lenses) and layers. Ice occupies more space than water, so the ground swells. Bumps and irregularities are formed, which can destroy buildings and roads (Figs. 2.8.8, 2.8.9).

Figure 2.8.8

A section of railway track damaged by permafrost effects

Figure 2.8.9

A building destroyed by uneven bulging and subsidence above permafrost

As the climate changes and temperatures increase, the permafrost thaws to ever deeper levels in the summer. The depth of previously constructed piles may not be sufficient, and they could begin to 'float', causing buildings to warp and collapse.

The problems do not end there. As climate warming advances, a particularly warm year may cause thawing of the permafrost to a deeper level than usual, and the trapped water escapes. This creates empty spaces underground, the land subsides, and bridge supports, power lines or even a small building can collapse into the ground. This effect is called **thermokarst**. It is highly dangerous, and its widespread nature due to global warming could not have been foreseen when buildings were designed and built in the Arctic in the past (Figs. 2.8.10, 2.8.11).

Leakage of water into the ground due to human action adds to the risk. Further weakening of the permafrost due to global warming could lead to major thermokarst problems associated with leakage from water and drainage pipes, which was less dangerous when the permafrost was well established. Rules that need to be followed include clearing snow from roofs and the areas around a building before it melts, as water should not be allowed to penetrate beneath the building.

What is to be done? We cannot stop climate change quickly, and its damaging impacts are increasing rapidly. Large amounts will have to be spent on direct freezing of soils, and on the design of more expensive buildings, which can cope with the new conditions.

Figure 2.8.10

A collapsed building in the village of Chersky (Russia)

Figure 2.8.11

The collapsed corner of a building in Yakutsk (Russia)

Permafrost can be maintained in the Arctic by relatively simple devices. Sometimes underground ventilation ducts are sufficient: very cold air from the surface freezes the ground to such low temperatures that it does not have time to thaw in the summer. This method is particularly suitable for roads on raised embankments. The soil of the embankment can be kept frozen by laying pipes of about 20 cm in diameter, 50 cm apart from one side of the embankment to the other.

The ground can also be frozen using devices called thermosiphons – vertical tubes, hermetically sealed at both ends, with their lower part in the ground, and their upper part rising two to three metres above the ground (Fig. 2.8.13). The tube is partially filled with a coolant (refrigerant), such as ammonia or liquid carbon dioxide. The thermosiphon freezes the ground in the winter due to the temperature difference between the relatively warm ground (a few degrees below zero) and the air (20–40°C colder). The liquid refrigerant at the bottom of the pipe evaporates due to the higher soil temperature, causing the soil to cool. The refrigerant vapour then rises upwards and condenses in the cold atmosphere above ground, after which it flows back downwards and the process repeats.

The thermosiphon thus transports cold underground, lowering the soil temperature by a few degrees more than would otherwise occur, and this is enough to ensure that the ground will not melt in the summer. The thermosiphon does not operate in the summer, because the air is warmer than the ground and the refrigerant inside the pipe does not circulate. During the summer the metal pipe conducts heat into the ground, but this effect is weaker than that achieved in the winter. This is a way of freezing the ground under roads and pipeline supports, and even under large buildings. But the thermosiphons much be installed no more than about one metre apart (Fig. 2.8.13).

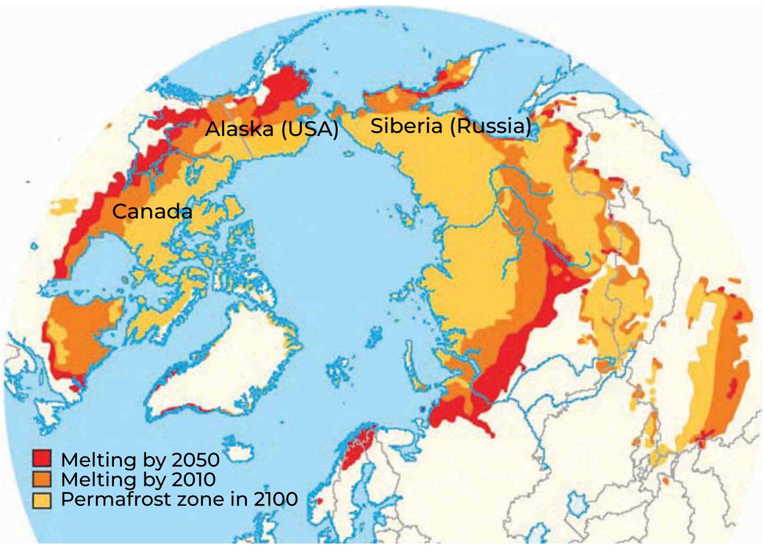


Figure 2.8.12

Future permafrost thaw across the Arctic. Red areas indicate regions thawed by 2050, orange areas thawed by 2100 and yellow areas still frozen by 2100

It would be wrong to think that thermosiphons offer an easy solution to the problem of melting permafrost. They need to be replaced often and, despite their simplicity, they are expensive. It has been estimated that permanent freezing of the ground under gas pipeline supports in Russia would require spending of $10 billion!

Thermosiphons are also only a temporary measure since they can only lower the temperature of the ground by a few degrees and will be powerless against more intensive warming. Roads will have to be mounted on special supports sunk deep into the ground – essentially, building an overpass on piles, which will increase construction costs manifold (Fig. 2.8.14).

Figure 2.8.13

Road with soil-freezing thermosiphons

Figure 2.8.14

Road standing on supports sunk deep into the ground

It is not always possible to ensure that the ground stays frozen, and freezing technologies are helpless in the face of storms and intensive coastal erosion. In more and more cases it is proving impossible to save buildings and infrastructure, and the only solution is to move people elsewhere.

Large amounts of greenhouse gases are released from the tundra soil in the process of permafrost melting, increasing the greenhouse effect and speeding up global warming.

Weather anomalies in the Arctic

You know already that wind as well as temperature must be considered when assessing the weather. Extreme cold without wind is far better than a powerful blizzard, which makes it almost impossible to do anything useful outdoors, even to travel from one place to another. Working in blizzards is dangerous and difficult. Strong winds are becoming increasingly common in the Arctic, requiring the use of ever greater quantities of special equipment, clothing safety gear and supplies to cope with prolonged snowstorms.

Humidity levels in the Arctic have increased, leading to an alternation of thaws and frosts. This means that roads, bridges, and power lines are often covered with a layer of ice, leading to more frequent accidents and breakdowns. Buildings and structures deteriorate more quickly due to the action of water and ice on microcracks. Water can penetrate the tiniest crack and then expands when it turns to ice, also expanding the crack. The ice melts, more water flows in, the new water freezes and the crack expands even more. The more often this cycle is repeated, the faster the building deteriorates.

Low-lying regions, such as the Yamal Peninsula, are increasingly affected by powerful spring floods, when huge territories are inundated with water to a depth of a metre or more. Yamal is now experiencing more snowfall and these large quantities of snow are now melting more quickly in the Arctic spring. Another problem in Yamal is the penetration of sea water into ground water, which leads to rapid erosion of the underground sections of all kinds of buildings.

How does climate change affect the indigenous peoples of the North?

Native peoples in the Arctic are suffering because of climate change since their way of life and traditional livelihoods are directly dependent on climate conditions. Hunting, fishing, gathering of natural harvests and reindeer herding provide people with food, are the main source of income and are crucial to preserving the traditions and culture of these peoples and of the territories where they live.

Figure 2.8.15 The way of life of the indigenous peoples of the Arctic

Reindeer herding is an important part of the livelihood and way of life of the natives of the Far North. More frequent thaws due to climate change mean that the ground is often covered by a layer of ice, which makes it hard for reindeer to find and eat lichens. Melting of the permafrost, changes in snow conditions and earlier melting and later freezing of river ice are disrupting reindeer migration routes between winter and summer pastures. Changes in reindeer migration routes and reduction in populations of marine animals, hunting of which is part of the way of life of people in the Far North, are forcing people to seek new sources of food and income.

What can be done to help the indigenous peoples of the Arctic to adapt to changing climate conditions?

1. Carry out information campaigns among the local population on climate change and its possible consequences so that they can prepare to address the challenges.

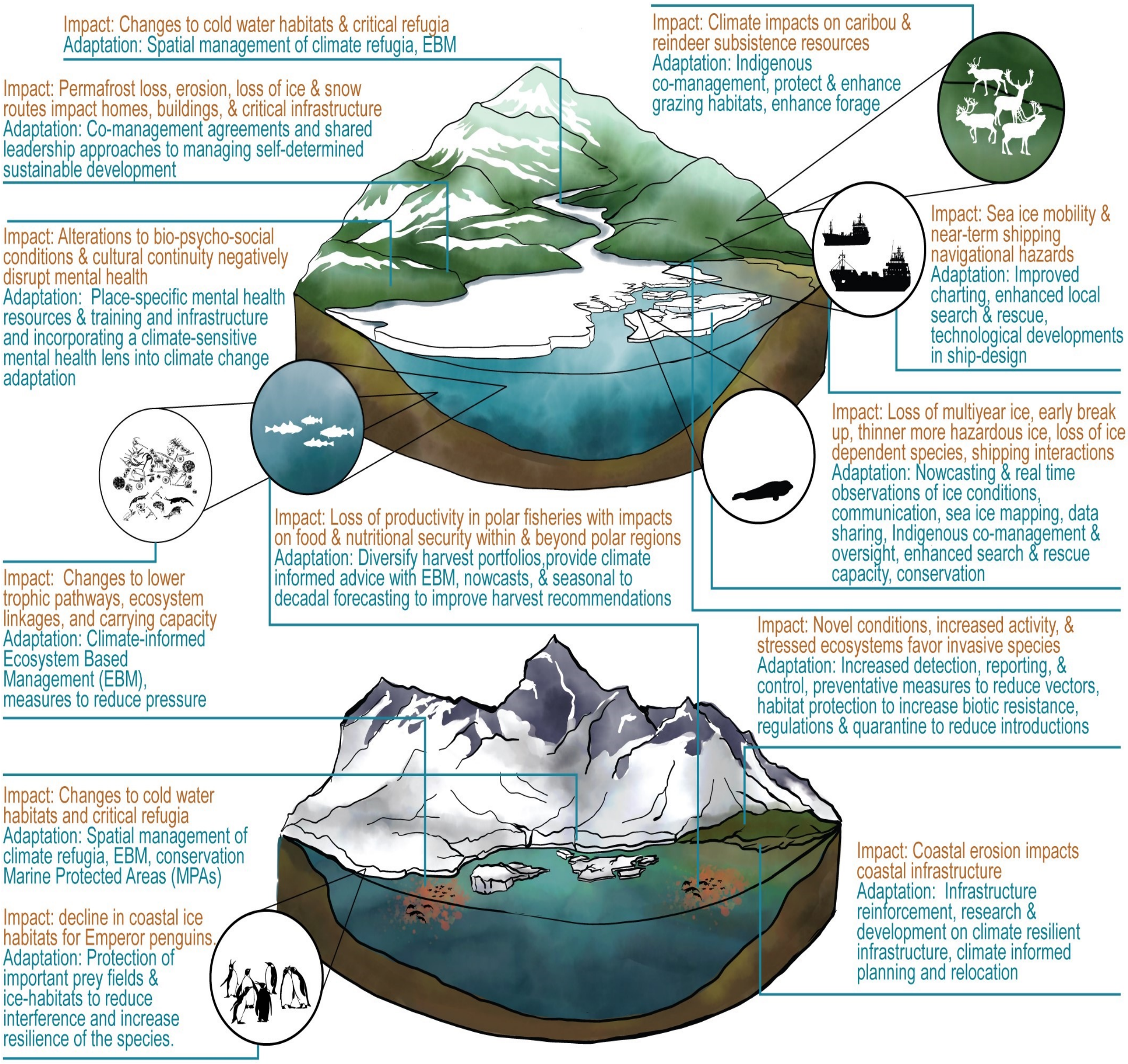
2. Develop eco-tourism in these areas.

3. Raise the availability of health care in the Far North, especially in remote areas and villages, and ensure reliable supplies of heat and electricity.

How do climate change impacts and potential to adapt in the Arctic compare to those in the Antarctic?

We are already familiar with polar amplification, which means that the Earth's poles are warming faster than the global average. We also already know that the Arctic has warmed nearly four times faster than the global average over the past four decades and that the Antarctic is warming twice as fast as the global average. Scientists compared climate change impacts and options for adaptation in the Arctic and Antarctic, which show some similarities and differences, e.g., because of different habitats (Figure 2.8.16).

Figure 2.8.16 Climate change impacts and potential for adaptation in the Arctic and Antarctic



What about the positive effects of a warmer climate?

It is true that climate change in the Arctic creates some opportunities. Less money can be spent on heating. Receding ice cover in the Arctic Ocean means that it can be used as a sea route between Europe and Japan and China and back. Infrastructure for marine traffic needs to be built along the Northern Sea route, including beacons, rescue equipment for emergency response, and harbours, where ships can ride out storms or take shelter in case of the sudden appearance of ice.

But the increasingly unstable Arctic climate and overall warming will also bring more frequent blizzards and sudden fluctuations of temperature.

The heating season may be shortened, but more unpredictable weather means that we must learn to adjust heating levels based on the real temperature outside the window and not on the date on the calendar. That will mean installing regulators on radiators, so that residents can adjust the temperature in their homes as required. Russian housing services are not ready for such measures, which call for extra work and equipment.

Climate change will bring more negative than positive impacts in all Arctic regions. Climatologists and economists have concluded: adaptation to melting of the permafrost, coastal erosion, and all the other possible negative consequences of climate change is possible, but it is very expensive. So, it is very important to find ways of minimizing global warming.

QUESTIONS

1 Where is climate warming happening faster:
in the world as a whole or in the Arctic?

2 Why does the air temperature increase rapidly when ice fields in the Arctic break up in the spring to reveal open water?

3 Why are polar bears affected by shrinkage of ice packs? Do they need ice?

4 What is the danger currently threatening seals in the White Sea?

5 Why is melting of the permafrost dangerous for buildings?
What would you recommend for buildings and other infrastructure to adapt to melting permafrost?

6 How does climate change affect the lives of indigenous peoples in the Arctic?
What could be done to help them adapt to the changing conditions?

TASKS

1

Experiment
Purpose of the experiment: To observe how the volume of water changes when it freezes.

Materials: Airtight glass bottle, water.

The procedure: Fill the glass bottle with water, seal it and put it in the freezer. What happens to the bottle when the water freezes? Why does this happen? Draw a parallel with the processes caused by permafrost.

2

Experiment
Purpose of the experiment: To observe the changes in the physical properties of materials when they freeze and thaw.

Materials: A plastic or paper box containing sour cream.
Note. Soil that has frozen and then thawed will not be the same as it was before freezing. Ice layers may appear in it, which will divide into water and soil when thawing occurs. Sour cream behaves in a similar way when it is first frozen and then thawed.

The procedure: Take a paper or plastic package of sour cream. Put it in the freezer. When the cream freezes, it will not be as a single piece: layers of ice will appear. When it thaws, the sour cream divides into a white liquid and a thicker white substance (once stirred, this mixture regains the appearance of sour cream, and it is perfectly eatable).

2.9 How climate change affects **cities and human health**

Half of the world's population lives in cities

Since time immemorial, the human population of every country and geographical region in the world has been divided into city and town people on the one hand, and country people on the other hand. Historically, cities have offered better conditions for crafts and industry – the first factories were in cities – and they have traditionally been safer places to live, being protected by walls. People living outside towns and cities have been focused on agriculture: growing crops and raising cattle.

Since the end of the 19th century there has been a major population influx to towns and cities. This process is called **urbanization**.

Figure 2.9.1 The old town of Berne in 1820

URBANIZATION
is the process by which towns and cities become dominant in a society. It is caused by the growth of industry in cities, development of their cultural and political functions and a deepening of the territorial division of labour.

By 2008, because of urbanization, the share of the world's population living in cities rose above 50% for the first time and continued to grow thereafter (Fig 2.9.2). By mid-2023, approximately 4.6 billion of the more than eight billion people worldwide lived in towns or cities. This represents 57% of the global population. According to the United Nations, the urban population is set to increase by almost 600 million by the year 2030, reaching a total of 5.2 billion (about 60% of the global population).

At present there are 34 cities worldwide with more than 10 million inhabitants. Most of these **megacities** are situated in Asia (21), Latin America (6) and Africa (3). The largest city is the urban agglomeration of Tokyo with a population of over 38 million (Table 2.9.1). This is followed by Delhi (26.5 million) and Shanghai (24.5 million). By United Nations calculations, the number of megacities is expected to increase to 43 by 2030. Delhi will then be the largest city in the world, with a population of almost 39 million.

So, the study of the climate in cities is important for at least half the population of our planet.

Figure 2.9.2 **Share of urban population in total population and the largest cities of the world in 2018**

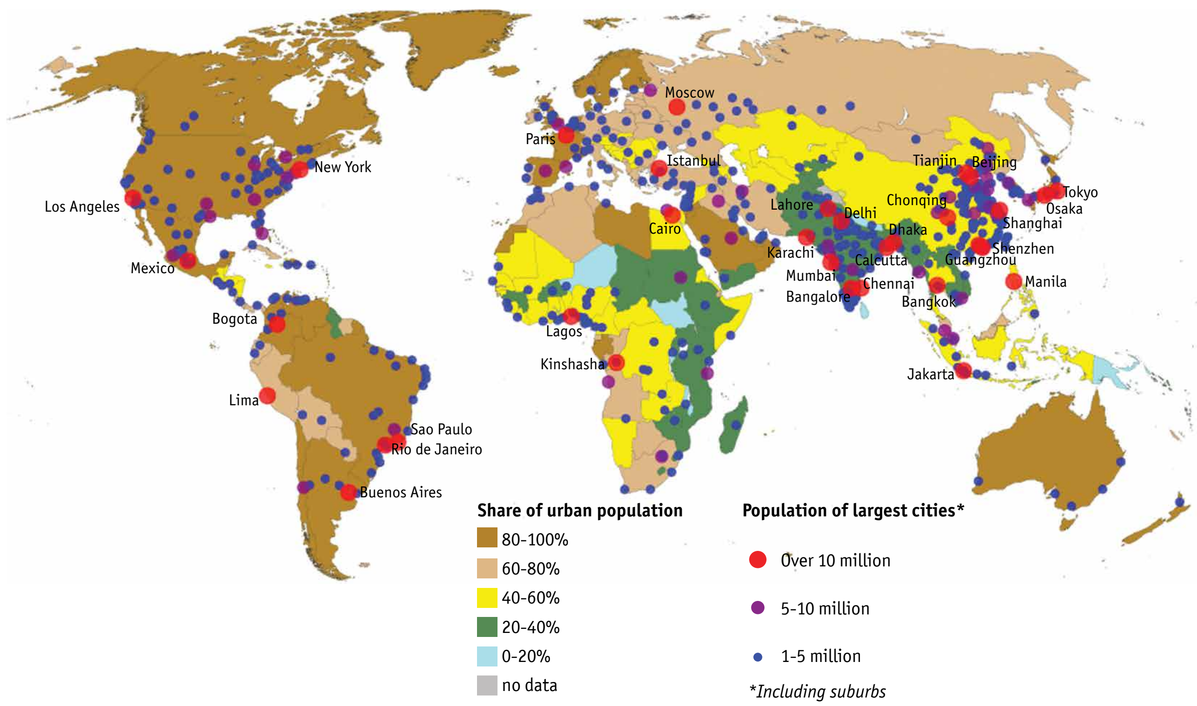


Table 2.9.1 The 15 largest cities in the world

№	City	Country	Population (million people)
1	Tokyo	Japan	38.1
2	Delhi	India	26.5
3	Shanghai	China	24.5
4	Mumbai	India	21.4
5	São Paulo	Brazil	21.3
6	Beijing	China	21.2
7	Mexico City	Mexico	21.2
8	Osaka	Japan	20.3
9	Cairo	Egypt	19.1
10	New York	USA	18.6
11	Dhaka	Bangladesh	18.2
12	Karachi	Pakistan	17.1
13	Buenos Aires	Argentina	15.3
14	Kolkata	India	15.0
15	Istanbul	Türkiye	14.4

Figure 2.9.3 Tokyo with more than 38 million inhabitants is the largest city by population in the world

Why are cities called heat islands?

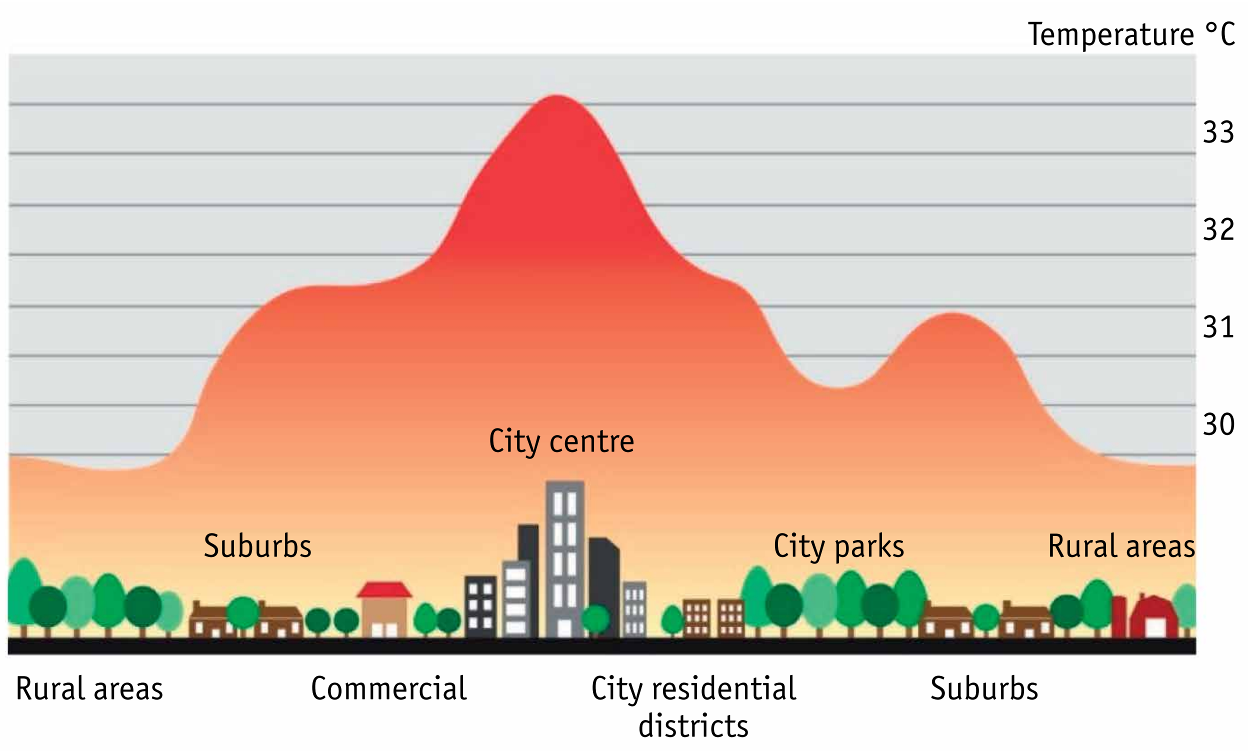
Cities are unique environmental hot spots on our planet, taking the word ‘hot’ quite literally: emissions of various substances from factories and motor vehicles ‘stagnate’ in the surface layer of the atmosphere above the city, creating a greenhouse effect, which raises its air temperature by several degrees compared with the surrounding territory. Scientists therefore call cities heat islands.

HEAT ISLAND
is an area in the centre of a big city, where the air temperature is higher than in outlying areas. The urban heat island effect is most noticeable in the evening and at night, especially in the spring and autumn, when the temperature difference between the centre of the city and outlying areas can be as much as 10–15°C.

The heat island effect in large metropolitan areas is being intensified by the process of climate warming.

We all know about the urban heat-island effect from personal experience: if you step out of a city building in the evening of a hot summer’s day, the temperature on the street is warm enough for a stroll in light clothing, but outside the city you would find it quite chilly outdoors in the evening without a jacket, even during the hottest summer month. This is because in an urban environment, surface air cools more slowly: it is kept warm by the walls and roofs of buildings that have soaked up heat during the day.

Figure 2.9.4 Air temperature distribution over a city (urban heat island)



The first studies of city climate

The first studies of city climate were carried out by Luke Howard (1772– 1864), an amateur meteorologist in London with a lifelong fascination with clouds and the weather.

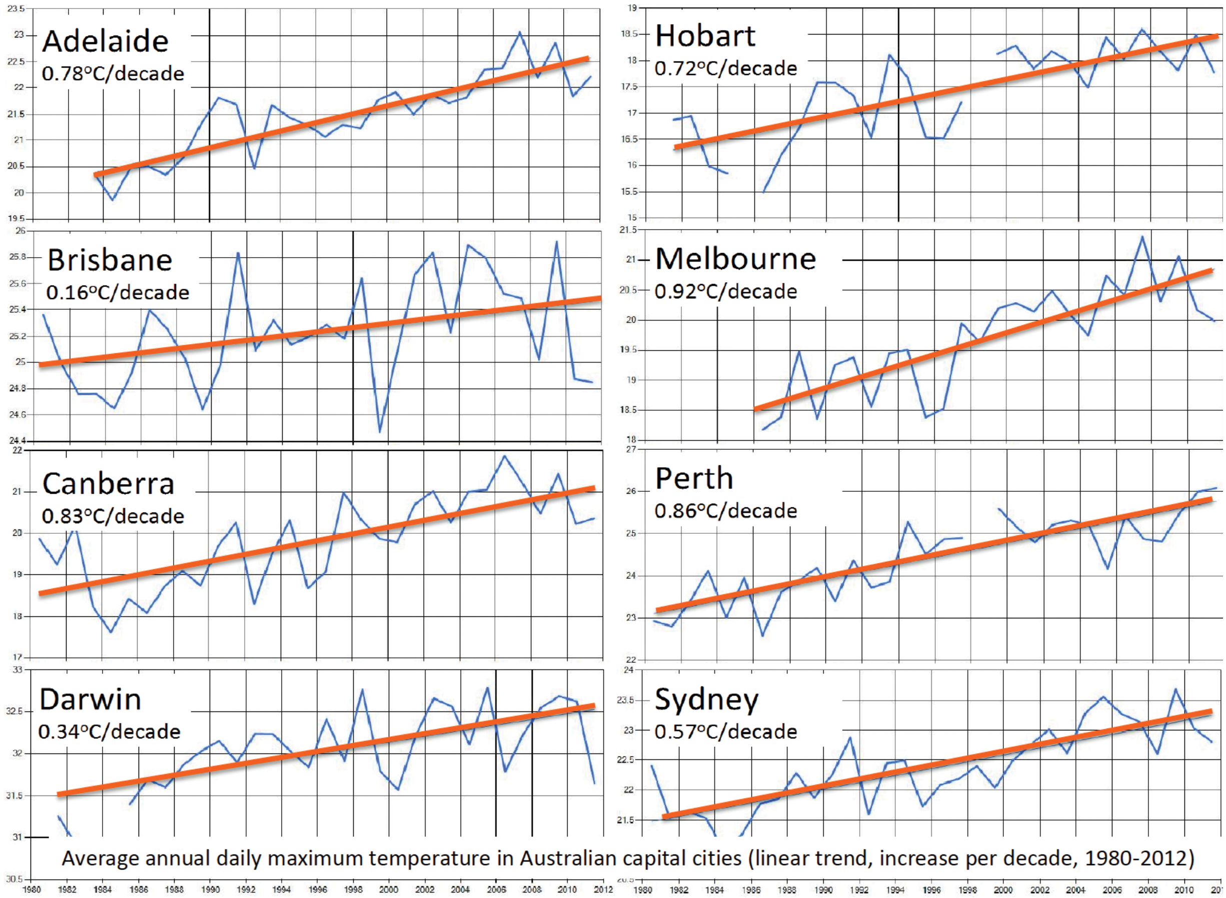
From 1806 to 1831, Howard carried out daily measurements of atmospheric pressure, air temperature and humidity, rainfall, and evaporation in the suburbs of London. For his observations he used newspaper reports on specific weather events. Howard did not study the specific climate in London, but carried out general climate studies, using London as the base for his observations. But what gives him a claim to be the founder of urban climatology was his attempt to compare the data from his own meteorological measurements with those of the Royal Society at a site in central London. The comparison revealed what modern researchers refer to as the ‘urban heat-island’ effect.

How does climate change affect the health of city dwellers?

Climate change has a substantial impact on human life and health. We already know that our health depends on lifestyle, food security, heredity, occupation, environment, and access to health care, but it is now becoming clear that it also depends on climate change.

Climate change is particularly noticeable in cities, and most of all in large cities. For example, the increase in air temperature in Moscow over the last century has been more than 2°C, while the increase in global average temperatures during the same period has been only 1.2°C. Air temperatures are also rising quickly in other major cities around the world (Fig. 2.9.5).

Figure 2.9.5 Change in average annual daily maximum temperature in major Australian cities in 1980–2012. Linear trend increase is per decade



Experts at the World Health Organization expect that global warming will cause extremely hot spells in cities to become more frequent, intense, and long-lasting. It is well-known that fluctuations in pressure, temperature and humidity can make living conditions in cities uncomfortable; there are more and more instances of excessive city heat taking a tragic toll among the elderly, young children, and people in poor health. Intense heat is accompanied by higher concentrations of pollen and other particles that cause allergies and asthma.

People who live and work in the city centre and those whose jobs require spending much time out of doors (road workers, construction workers, delivery men) are particularly at risk on hot days.

If a heat wave lasts for more than a week, it can lead to heart problems and even death among the elderly, and people with poor health.

According to a study published in the journal, Nature Medicine, nearly 62,000 people died of heat-related causes in Europe during the summer of 2022. The study analysed temperature and mortality data between 2015 and 2022 for 35 European countries, representing a total population of 543 million, and used it to create epidemiological models to calculate heat-related deaths. Researchers found that Italy was the hardest-hit country, with around 18,000 deaths, followed by Spain with over 11,000, and Germany with around 8,000. The extreme heat disproportionately harmed the elderly and women. Of the nearly 62,000 deaths analysed, the heat-related mortality rate was 63% higher among women than men. Age was also an important factor, with the death toll rising significantly among people aged 65 and over.

Timely forecasting of a coming heat wave is of great importance, since it gives medical personnel a chance to prepare for it. The World Meteorological Organization (WMO) recommends that such a warning forecast be given at least two days before the period of intense heat begins.

The USA, Canada, France, and some other countries have already taken steps to address the challenges posed by the heat island effect in the context of global warming. For example, the US city of Philadelphia has advocated a system of ‘good offices’ during heat waves: the media regularly report on the changing weather conditions and offer advice on how to avoid heat-related illnesses. The number of a telephone hot line is published in the newspapers and displayed prominently on a large screen in the city centre. Emergency medical services and fire departments take on extra staff. Special air-conditioned premises are provided for elderly people, who are brought there by a special, free-of-charge transport service to take a break from the heat.

Temperatures that people from a hotter climate consider normal can be termed a heat wave in cooler areas if they are outside the normal climate pattern. In the USA, for example, the definition of a heat wave depends on the region. In the northeast, it is typically defined as three consecutive days of temperatures reaching or exceeding 90°F (+32.2°C). In California, where the climate is hotter, a heat wave has a higher threshold of 100°F (+37.8°C) for three or more consecutive days. The National Weather Service issues heat advisories and excessive heat warnings when unusual periods of hot weather are expected.

Precautions to take in hot weather

- Wear clothes made of natural fabrics: they help to prevent overheating by allowing the skin to breathe.
- Keep a bottle of water with you, preferably water that is not too cold. A person should drink at least three litres of water a day in hot weather.
- Keep out of direct sunlight so far as possible. The sun is at its strongest from midday until about 1600 hours, so try to stay indoors during this time.
- Always wear a hat or headpiece.
- Do not buy perishable products: bacteria multiply very quickly in high temperatures, so there is a risk of severe food poisoning.
- Eat plenty of fruits, vegetables, various salads, and cold soups.
- Avoid oily and salty foods.
- Do not overdo sport and physical training.
- Stay relaxed: any nervous stress increases the risk of heat stroke, sun stroke and cardiovascular disorders.
- Do not sit directly under air conditioning: the temperature difference between the hot streets and an air-conditioned room is very large, and such temperature swings can induce colds and pneumonia.

Climate change has negative impacts on human health (Fig. 2.9.6). Dangerous infectious diseases, such as encephalitis and malaria, spread to areas where they were not previously present, and the period of the year when there is danger of infection becomes longer.

Climate change intensifies infection risk

Tick-borne encephalitis is a viral infection. The virus enters the human body through a bite from an infected tick. Encephalitic ticks, the main virus carriers, live in taiga and forest areas of Siberia, the Urals, and the Russian Far East. But there have recently been an increasing number of cases of infection in the central part of European Russia, the North-West and the Volga region. Cases of tick-borne encephalitis are being recorded for the first time in parts of European Russia, and scientists attribute this to global warming.

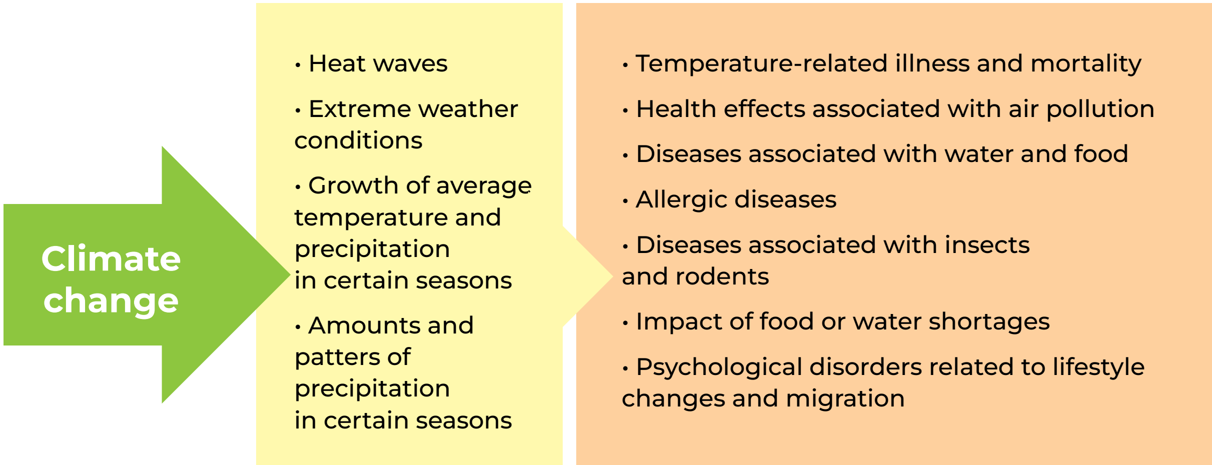
Warmer weather in the winter and spring favour the spread of ticks: they are more likely to survive the winter and can multiply rapidly in the spring. Typically, only a small fraction of all ticks is infected with encephalitis. But an increase in the total number of ticks leads to an increase in the number of infected individuals.

Malaria (from the Italian '*mala aria*', meaning 'bad air'), also known as swamp fever, is an infectious disease transmitted to humans by bites of malarial mosquitoes, causing a high fever. Malaria transmission depends on the presence of malarial mosquitoes in a given area and ambient temperatures, at which the viral agent that causes the disease can develop in mosquitoes.

Malaria usually occurs in tropical countries, but the disease is much less common in tropical highlands, where colder temperatures slow down the mosquito and the development of the parasite within it.

As the climate warms, the boundary of the area where malaria occurs moves into milder climate zones further and uphill from the equator, and the 'malaria season' (the time of year when outbreaks are most likely to occur) grows longer. Some studies have shown that malaria has spread into higher altitude areas in Kenya, Colombia, and Ethiopia, where it was previously too cold for the disease to thrive. This puts millions of people at risk of the disease, necessitating extra measures to prevent outbreaks of malaria.

Figure 2.9.6 Impacts of climate change on human health



A recent study on the health impacts of climate change published in the Lancet Medical Journal provides a set of indicators that help to understand the impacts of climate change on human health, such as heat mortality, food insecurity and air pollution exposure.

On extreme heat, for example, the study finds that in the Small Island Developing States, 103 days of health-threatening temperatures every year are attributable to climate change over 2018-2022. Across Europe, North America and Oceania, this number is less than 30.

The study estimates that under a 2°C warming scenario, for example, 525 million additional people will experience food insecurity by 2041-2060, compared with the 1995-2014 average.

A combination of climate change, urbanization and human movement are driving up the incidence of diseases such as dengue fever. The study finds that 'cases of dengue have doubled every decade since 1990, and almost half of the world population is now at risk of this life-threatening disease.'

Floods also pose a threat to human health, since flooding disrupts water supply and sewerage systems, which increases the risk of intestinal diseases. In some parts of the world, flooding may bring poisonous snakes and crocodiles with it, as happened in Australia in 2011.

Changes in the environment and lifestyles can induce psychological stress and depression. You have probably noticed that sometimes, when the weather is bad, you don't want to go anywhere or do anything. So how will people feel if they experience bad weather more often?

How does climate change affect the urban economy?

Extreme weather events can disrupt transport, electricity, and water supply in cities. Flooding may inundate buildings, roads, railways, seaports, and airports. Higher temperatures lead to faster deterioration of road surfaces, which need more frequent repairs. Sudden temperature drops in the winter cause the formation of ice that damages power lines, leaving homes, schools, hospitals, and businesses without electricity.

Residents in northern countries with colder climates may be able to reduce the cost of heating their homes as air temperature in the cold season rises. But cities in southern countries with hot climate conditions will face higher costs as there will be greater need for air conditioning in the summer.

In-depth studies of climate change impacts on cities over the last decade can help improve our understanding of the possible consequences of global warming and offset some of the costs. For example, the cost of clearing damage caused by flooding can be partly compensated by savings on heating in the winter.

How can we adapt and live in healthier and climate-resilient cities and settlements?

IPCC scientists noted in the AR6 that rapidly growing urban populations and unmet needs for healthy, decent, and sustainable housing and infrastructure pose a persistent challenge. But urbanization also offers many opportunities to build adaptation measures into the planning and development of cities and their infrastructure. This is a critical priority, given that an additional 2.5 billion people are projected to be living in urban areas by 2050, with up to 90% of this increase concentrated in Asia and Africa.

Many cities and urban settlements are already taking actions to adapt to current and near-term climate impacts and risks as part of their social and economic planning and policies. These actions include hard engineering interventions and planning, such as further development of urban public transportation, engineering flood defence, redesigning and fortifying buildings, setting up cyclone shelters, introducing hurricane-resistant building codes, developing standards, regulations, and guidelines for construction, improving stormwater management, drainage and flood protection systems, and, where relevant, strengthening infrastructure to withstand permafrost conditions. There is also growing interest in adaptive urban design and nature-based solutions aimed at green cooling, such as green roofs, walls, and parks. Expanding green and natural spaces simultaneously enhances biodiversity, improves air quality, and moderates the hydrological cycle; it also helps reduce health risks associated with heat stress and respiratory illnesses, and mitigates mental health challenges arising from congested urban living. Green roofs in the USA (Fig. 2.9.7), are an example of how cities are working to mitigate the effects of stormwater runoff, which is a major polluter of waterways, while at the same time keeping buildings cooler.

Health-related measures include redesigning and retrofitting homes, schools, and health care facilities to reduce the impacts of extreme heat, managing increases in infectious diseases such as malaria, and improved access to water and sanitation services. Actions taken in different sectors to address the risks of climate change can generate benefits for human health and well-being. Transitioning away from internal-combustion vehicles and fossil fuel-powered generating stations to renewable energy mitigates greenhouse gas emissions, improves air quality, and lowers the risks of respiratory illnesses. Policies and designs that facilitate active urban transport (walking and bicycling) increase efficiency in that sector, reduce emissions, and improve air quality and the physical and mental health of residents. Energy-efficient buildings and urban design improve indoor air quality and reduce risks of heat stress and respiratory illness. Food systems that emphasize healthy, plant-centred diets reduce emissions in the agricultural sector while helping in the fight against malnutrition.

Figure 2.9.7 Green roofs in the USA help with stormwater runoff and to cool buildings

QUESTIONS

1. Does more of the world's population live in cities or outside cities?

2. Where is it warmer - in the city or in the city suburbs?

3. Why are heat islands bad for human health?

4. Can you list three measures for adaptation to climate change in cities?

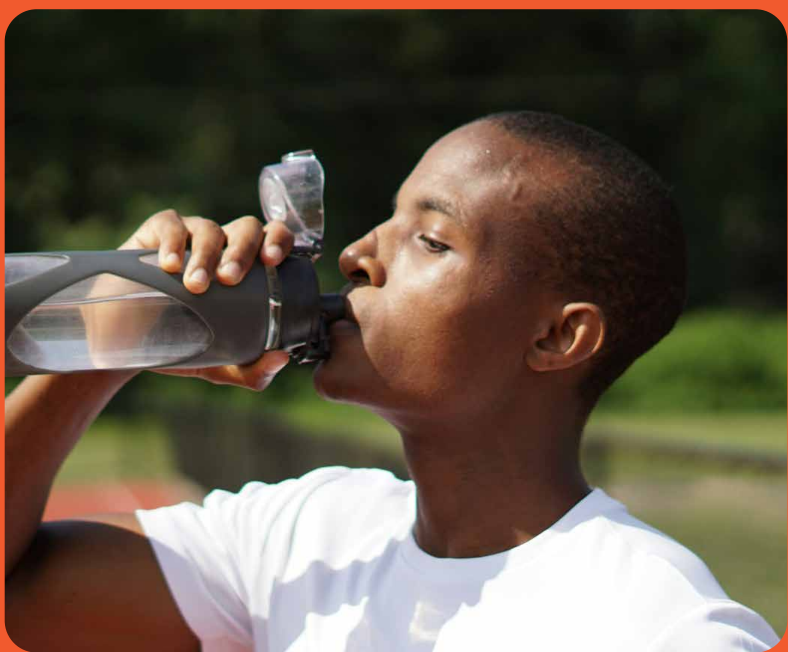
5. What are the negative impacts of global warming on human health? What are vector-borne diseases?

6. What precautions should be taken in hot weather?

TASKS

1 If you take your summer holiday in the countryside, try placing a thermometer outdoors in the shade at the level of a person's height above the ground and write down the temperature it shows in the early morning (before the sun starts to raise the air temperature). Compare it with the forecast for night air temperatures in the nearest large city on the same day. Are the figures different? Why?

2 Using textbooks, reference books and the Internet, find out and write down how you can help someone suffering from heat stroke, sunburn, frostbite, and severe allergic reaction to pollen, or someone who has been bitten by a tick. What preventive measures can you take to protect your health during a period of intense heat?



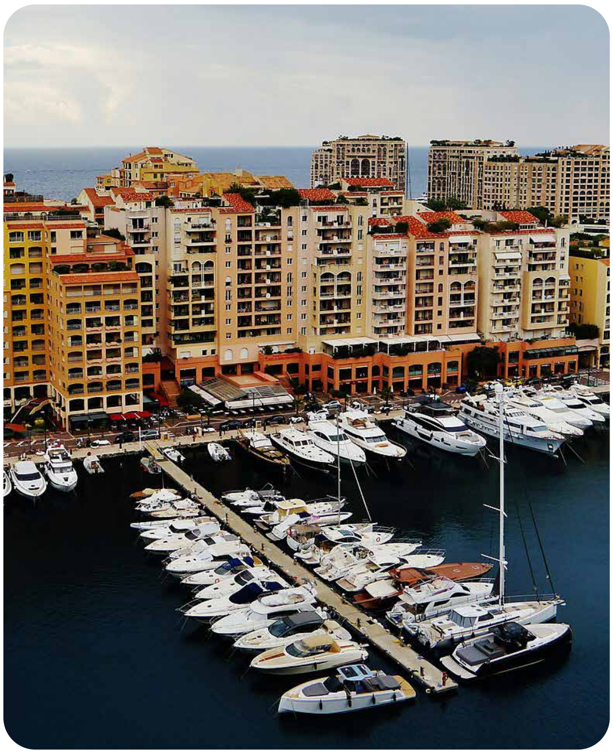
2.10 How climate change affects **social problems**

Different worlds: developed and developing countries

There are about 200 countries in the world. All countries are different from one another in geographical location, territory, natural environment, climate, population, economy, standard of living, history, and traditions. They have contributed in different levels to climate change and are all affected differently by it. They also differ in their capacity to cope with new climate impacts.

Countries are often divided into two large groups by their level of development: so-called 'developed countries' and 'developing countries'.

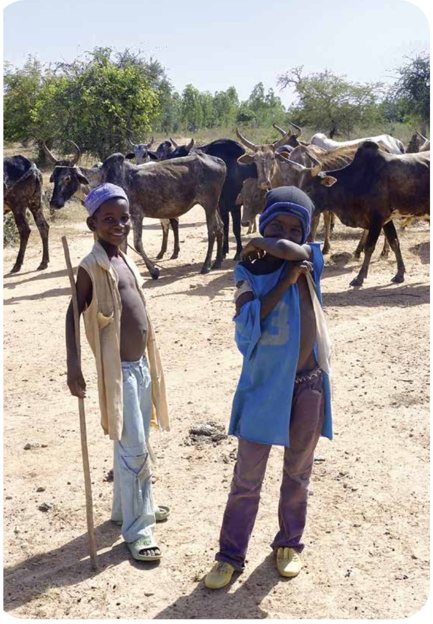
Developed countries are relatively rich, with favourable living conditions and strong economies, in which industry, services and the financial sector play a major role. Their residents generally have social security, access to good health care and education, fulfilling work opportunities, and relatively high incomes that enable them to spend money on restaurants, shopping, or travel. The group of developed countries usually includes, but is not limited to, the USA, Canada, Australia, New Zealand, the United Kingdom, European countries, Japan, Singapore, and Israel. Some countries in Eastern Europe with so-called '**transition economies**' represent a sub-group within the group of developed countries. The term 'transition economies' comes from these countries' transition since the 1990s from centrally planned to market economies.



Developing countries as a group are at an earlier stage of their economic and social development compared to developed countries. Many of these countries are still heavily dependent on agriculture, commodities trading and mining. Large sections of the population have a lower standard of living, uneven access to health care, fewer social programmes, and fewer opportunities for education and employment.

The group of developing countries is very diverse. These include **emerging economies** (newly industrialized countries) such as China, India, South Korea, Türkiye, Brazil, Argentina, and Mexico, with rapid growth of industry and services. China and India are among the world's ten largest economies today. Many things we use every day – clothes, shoes, dishes, furniture, appliances, and toys – are made in these countries, particularly in China. China leads the world in the volume of manufactured goods it produces every year, followed by the USA.

And then there are 46 countries considered to be the **least developed** in the world. They include small island states, landlocked mountainous countries, as well as countries with overcrowded territories and unfavourable climate conditions. These countries are very poor, their economies are weak, and their people and way of life are highly vulnerable to climate change impacts and natural disasters. Most least-developed countries are in Africa and Asia, and the poorest of them, according to the World Bank, are Afghanistan, Burundi, Chad, the Democratic Republic of the Congo, Liberia, Malawi, Mozambique, Niger, and Somalia. Poverty in most of these countries is widespread, with most of the population living on less than two dollars a day. Many people are short of food, clean drinking water, hospitals, and schools. Families living in poverty try to have as many children as possible who will help their parents with housework, contribute to family income, and support them in old age. Poor sanitation, lack of food and clean water, and uneven access to health care mean that many children die before they can grow up, so having many children is a way of ensuring that at least some of them will survive. About 880 million people (12% of the world's population) now live in the world's poorest countries, which contribute less than 2% to the global economy.



Social inequality

In 2023, the world's population crossed eight billion. The vast majority of the world's people – 6.64 billion, or 83% of the total – live in developing countries and only 17% or 1.36 billion people (the so-called 'golden billion') live in developed countries.

Not surprisingly, the 17% of people living in rich countries consume the lion's share of the world's production, given their high incomes and lifestyle requirements. Operating industrial enterprises and creating the daily production for people in rich countries requires tremendous amounts of resources and energy. The largest energy consumers include Iceland, Norway, Canada, the USA, and wealthy nations in the Middle East such as Oman, Saudi Arabia, and Qatar. The average person in these countries consumes as much as 100 times more than the average person in some of the poorest countries. For example, the average American needs 3.5 times more resources during their lifetime than the average inhabitant of the Earth, and the average American uses nine times more energy than the average Indian. So, the contribution of people living in developed countries to global greenhouse gas emissions (their 'carbon footprint') is much higher than that of people in developing countries, and they bear greater responsibility for the consequences of climate change.

The gap between the quality of life of the world's rich and poor is huge. Average incomes in the richest 20 countries are 37 times higher than those in the poorest 20. So, for every $100 in income received by the average citizen of Europe or the USA, a resident of Nepal or Ethiopia receives only $2.50. The incomes of the 500 richest people in the world exceed the total income of the 416 million poorest people on the planet.

High birth rates in many developing countries mean that their rate of population growth is 3.5 times higher than that of developed countries. The populations of many poorest countries in Africa and Asia could double in less than 40 years. So, the numbers of the poorest people on the planet continue to increase.

The gap between the world's rich and poor is huge. People in developed countries, who are just 17% of the world population, consume the greater part of the world's production and more than 70% of all energy, while nearly 2.5 billion people worldwide are living on less than two dollars a day. According to the Food and Agriculture Organization, 770 million people lack access to clean drinking water, and 821 million people do not have the food they need to live an active and healthy life.

It would be a mistake to think that poverty is limited to the least developed countries. Rich countries also have backward regions and poor people. In the USA, for example, the Census Bureau put the number of poor people at 38 million in 2021, or about 12% of the total population. In Germany, nearly one in seven people, or 13.5 million, were living on or below the poverty line in 2022. Often the poorest people in developed countries are those who came there to work from developing countries, as well as people living in rural areas and declining industrial cities, where mines and factories are closing because they are unprofitable.

But the situations of a poor American and a poor African are quite different! The poverty line in the USA is an annual income of $22,000 for a family of four people, or about $15 per day per person. That really is very little in view of the high cost of essential goods in that country. But, to a poor person in the developing world, an American pauper, with their own accommodation, complete with toilet and bath, seems like Rockefeller.

Stark inequalities in living conditions – the unequal distribution of incomes and opportunities between the people of our planet – have grown to become one of the most pressing social problems in the world today. As noted in the *Human Development Report* of the United Nations Development Programme in 2013: "Every person has the right to live a fulfilling life according to his or her own values and aspirations. No one should be doomed to a short life or a miserable one because he or she happens to be from the 'wrong' class or country, the 'wrong' ethnic group or race or the 'wrong' sex." Unfortunately, climate change only intensifies social inequality and complicates the task of overcoming poverty. The recent COVID-19 pandemic exacerbated these problems and, over two years, reversed some of the gains in social and economic development, poverty alleviation and reducing inequalities (*UNDP Human Development Report 2021-2022*).

Climate change makes social problems worse

We have already seen how every region and country in the world is experiencing the impact of climate change, but we have also seen how some of them – coastal, Arctic, mountainous or agricultural regions or countries – are more affected than others. This happens because the lifestyle and economy of the local population depends greatly on natural conditions and climate, so that any change leads to major problems for the economy and for society.

People in poor countries and regions depend mainly on agriculture for their livelihoods, so any drought, flood or hurricane can instantly deprive these people of their only source of income. Countries such as Bangladesh, Haiti, or Chad are not only among the first to feel the effects of climate change, but also lack the resources and capacities to address the potential risks.

Climate change in poor countries has especially major impacts on women, who are mainly responsible for raising children, looking after the sick and elderly, growing crops, and collecting water and fuel, and feeding their families. All these tasks are seriously affected by climate change.

In all regions, even in high-income countries, small children, the elderly, and people with disabilities may be at particular risk because their health is highly dependent on weather conditions.

CLIMATE INJUSTICE
means people who are least responsible for global warming may suffer the most because of it.

Climate migration

Climate change is causing tens of millions of people to migrate to escape the effects of storms, droughts, and floods. According to research by the Columbia Climate School of Columbia University, around 23 million people around the world moved away from their homes in 2017 due to sudden extreme weather events. Another 44 million or so were displaced due to 'humanitarian crises', likely exacerbated by the cascading effects of climate change. Their numbers may reach 200–250 million by 2050.

Areas threatened with mass migration include the Mekong and Ganges River deltas in South-East and South Asia. These are densely populated agricultural areas, where a predicted rise of two metres in water level in these rivers will lead to flooding of large areas of arable land. People who work in these fields will be forced to seek new places to live and work.

Frequent droughts or floods, with particularly serious consequences for agriculture, will force many people in rural areas to move to cities in search of work. Such migration leads to the creation of whole neighbourhoods of poor migrants – slum areas with poor basic services and a high crime rate.

An increasing number of people from the Caribbean islands are leaving their homes due to more frequent tropical storms and tornadoes as these countries have only limited capacities to cope with tougher climate conditions.

Figure 2.10.1 Slums in Rio de Janeiro (Brazil)

Figure 2.10.2

A camp of migrants who were forced to leave their homes due to a severe drought (Somalia, 2011)

Figure 2.10.3

The aftermath of Hurricane Haiyan (The Philippines, 2013)

Australia and New Zealand have received climate migrants from the island states of Oceania. Islands in the Tuvalu and Kiribati Archipelagos, located not far from Australia, are gradually being submerged by rising water levels in the ocean. Environmentalists in Australia are pressing their government to allocate a special quota for these climate refugees. Similarly, the Government of the Maldives has agreed with Sri Lanka (also an island nation) on resettlement of its people if there is imminent danger of this island chain disappearing under the sea.

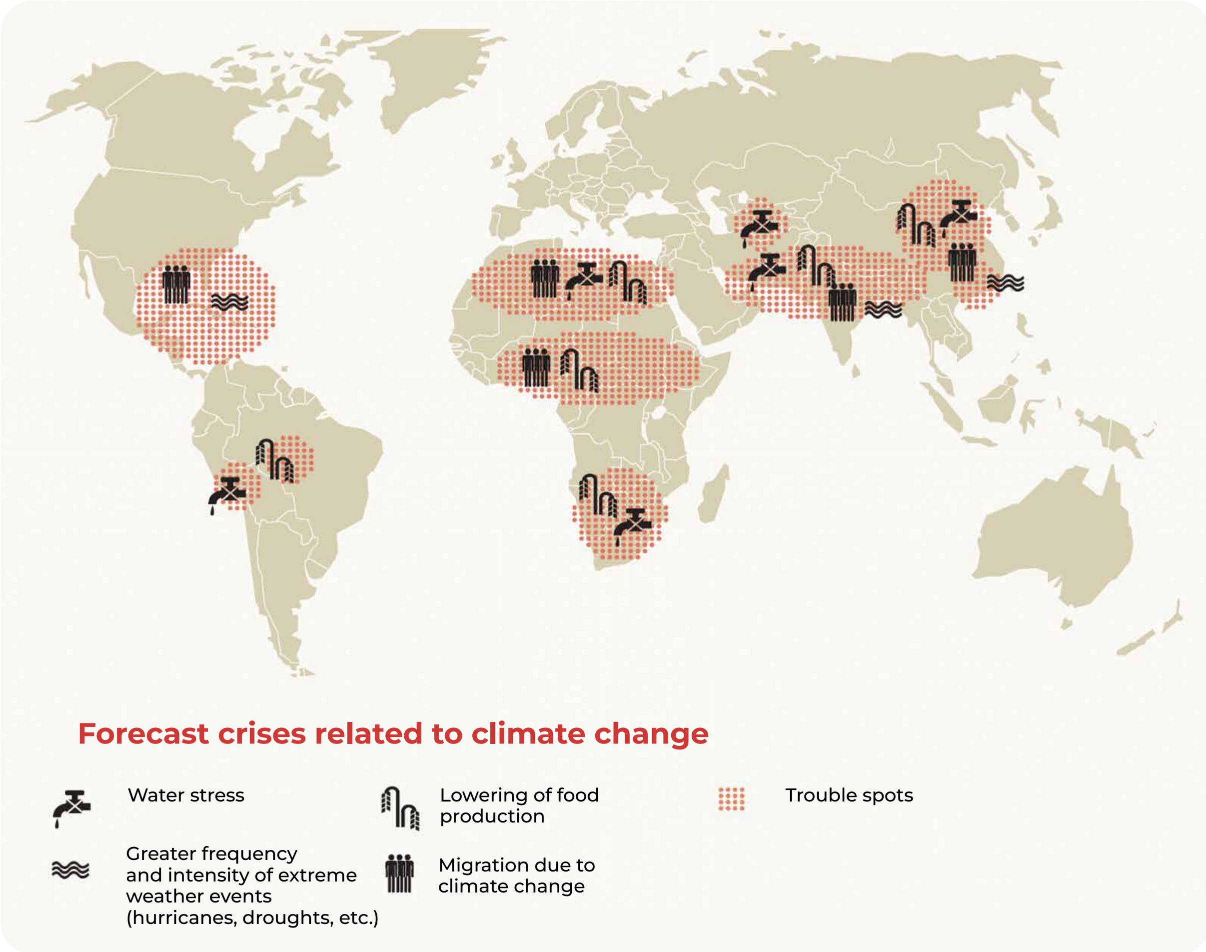
The island nation of Kiribati consists mainly of coral islands, which are only two metres above sea level on average, so that rising sea levels could inundate them within the next 50 years. In 2012, the government of the islands decided to buy land in the Republic of Fiji, where the inhabitants of islands, which may be lost to the sea, can be resettled.

New conflicts

Climate change can cause serious conflicts between people in different regions, particularly over land rights, water scarcity and climate migration, with widespread social consequences (Fig. 2.10.4).

Regions marked in red are particularly at risk of crises related to climate change. These are regions threatened by prolonged droughts, water shortages, rising sea levels, soil salinity and crop failures, lack of access to energy and other factors that could provoke political and social crises, and increase migration flows.

Figure 2.10.4 Areas of potential crises related to climate change



International cooperation for social assistance

Special programmes of assistance for the most vulnerable populations are needed to reduce the social risks arising from climate change. These may include: training and professional reorientation for people in rural areas, giving them alternative livelihoods to agriculture; projects to resettle the inhabitants of threatened regions; the creation of jobs in poor areas; research to develop more drought-resistant crop varieties; and setting up early warning systems for natural disasters. But all these measures require money that poor countries and poor people do not have.

There are various funds and financial instruments to help developing countries overcome social problems associated with the adverse effects of climate change. The main donors are the governments of developed countries, large companies, and international organizations, primarily the United Nations.

QUESTIONS

1 How are developed countries different from developing countries?

2 Do most of the people in the world live in developed or developing countries?

3 Which countries are the most vulnerable to climate change? Why?

4 Why do the consequences of climate change have the greatest impacts on the world's poor?
What social problems does climate change make worse?

5 Animals and plants cannot adapt to rapid changes in climate, but how about people?

TASKS

1

On a map of the world, underline the top 20 countries in terms of economic development and colour them using a green crayon. On the same map underline the 20 countries that are the top emitters of greenhouse gas emissions (data can be found in Wikipedia) and colour them red.

Is there a lot of overlap? How many of the leading countries of the world are now a 'dirty brown', indicating that they cause the most harm to the Earth's climate?

Explain why these countries are the most to blame for ongoing climate change.

2

Imagine that you are working for an international fund that allocates money for projects to combat the consequences of climate change. What projects to help poor countries would you finance first and foremost?