Index

The big picture
Causes and consequences of climate change
Additional causes of climate change and possible solutions
Impacts of climate change on phenology (HL)
Summary and key terms
Checklist
Investigation
Reflection

The big picture

? Guiding question(s)

- What are the drivers of climate change?
- What are the impacts of climate change on ecosystems?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

In 1958, scientist Charles David Keeling began measuring the concentration of carbon dioxide at the Mauna Loa Observatory in Hawaii. His measurements revealed a steady increase in CO_2 levels year after year, forming what is now famously known as the Keeling Curve (**Figure 1**) (see section C4.2.19–20 (/study/app/bio/sid-422-cid-755105/book/human-impact-on-the-carbon-cycle-id-46637/)). On the first day of operation in 1958, his team recorded an atmospheric CO_2 concentration of 313 ppm and in 2023, CO_2 concentration has surpassed an astounding 420 ppm!

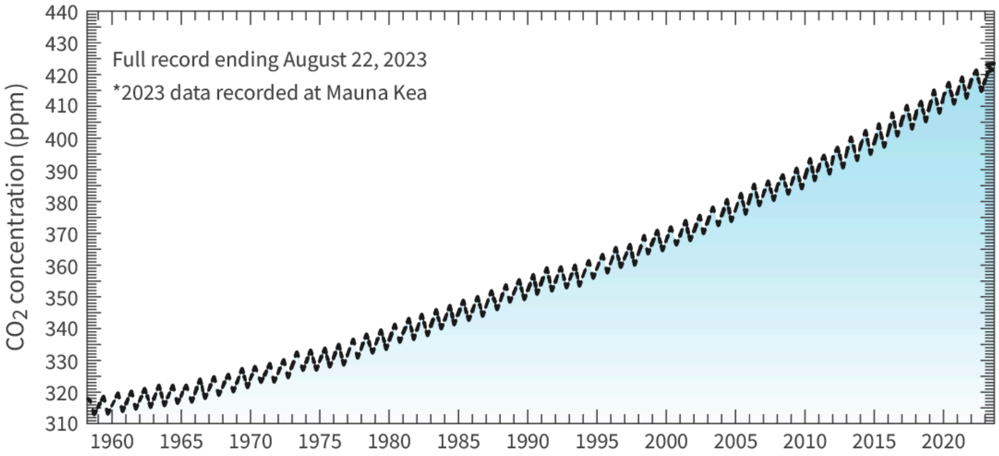


Figure 1. The Keeling Curve.

More information for figure 1

The image is a line graph displaying the Keeling Curve, which represents the concentration of carbon dioxide (CO2) in the atmosphere from 1960 to 2023. The X-axis indicates years, ranging from 1960 to 2023, while the Y-axis represents CO2 concentration in parts per million (ppm), spanning from 310 ppm to 440 ppm. The graph shows a consistent upward trend in CO2 levels, starting at about 315 ppm in 1960 and surpassing 420 ppm in 2023. There are notable seasonal oscillations in the data points, which are indicated by a jagged pattern along the trend line. A label indicates that the full record ended on August 22, 2023, and notes that the 2023 data was recorded at Mauna Kea.

[Generated by AI]

The method used at the Mauna Loa Observatory provides measurements of the overall atmospheric CO_2 concentration, which is influenced by various global emission sources.

Now, there are even more advanced ways of tracking emissions. Direct emissions, for example, quantifies the amount of CO_2 or other greenhouse gases emitted from specific sources such as power plants, industrial facilities or vehicles. Direct emissions can be measured using techniques like gas analysers, emission testing equipment or air sampling near emission points. Direct emissions measurement provides information about the emissions from individual sources, allowing for a more targeted assessment of their environmental impact.

Overview
(/study/ap
422-
cid-
755105/o

Remote sensing and satellite monitoring with satellite instruments can also be used to detect and measure greenhouse gas concentrations, providing a global perspective and identifying emission hotspots (**Figure 2**).

Figure 2. This satellite in space is Japan's Greenhouse Gases Observing Satellite and is used to monitor carbon emissions.

Source: "Orbiting Carbon Observatory (OCO)-2" (https://commons.wikimedia.org/wiki/File:Orbiting_Carbon_Observatory_(OCO)-2.jpg) by NASA/JPL-Caltech is in the public domain

This ongoing data collection has become a powerful symbol of human-enhanced climate change, highlighting the impact of our actions on the Earth's atmosphere. Combining these methods enhances the accuracy and reliability of carbon emission measurements, providing a more comprehensive understanding of emissions.

How did we reach such unprecedented levels of CO_2 in such a relatively short span of time?

What do these levels mean for our planet's future?

In this subtopic, you will delve into the causes and consequences of climate change, forming a deeper understanding of this pressing global issue.

Student view

To learn more about the Keeling Curve, watch **Video 1**.

Overview
(/study/ap
422-
cid-
755105/o

Video 1. The Keeling Curve: the story of CO_2.

Prior learning

Before you study this subtopic make sure that you understand the following:

- Ecosystems as carbon sinks and carbon sources (see section C4.2.17—18 (/study/app/bio/sid-422-cid-755105/book/the-carbon-cycle-id-46636/)).
- Conditions required for coral reef formation (see section B4.1.5 (/study/app/bio/sid-422-cid-755105/book/coral-reef-formation-id-44706/)).
- Range of tolerance of a limiting factor (see section B4.1.3—4 (/study/app/bio/sid-422-cid-755105/book/limitations-of-adaptations-and-range-of-tolerance-id-44705/)).

D4. Continuity and change: Ecosystems / D4.3 Climate change

Causes and consequences of climate change

Student view

D4.3.1: Anthropogenic causes of climate change
D4.3.2: Positive feedback cycles in global warming
D4.3.3: Tipping points
D4.3.4: Habitat changes

Overview
(/study/ap
422-
cid-
755105/o

Learning outcomes

By the end of this section you should be able to:

- Define anthropogenic climate change and describe its causes.
- Outline the positive feedback cycles in global warming, with examples.
- Describe the transition from net carbon accumulation to net loss in boreal forests as an example of a tipping point.
- Explain the melting of landfast ice and sea ice as examples of polar habitat change.

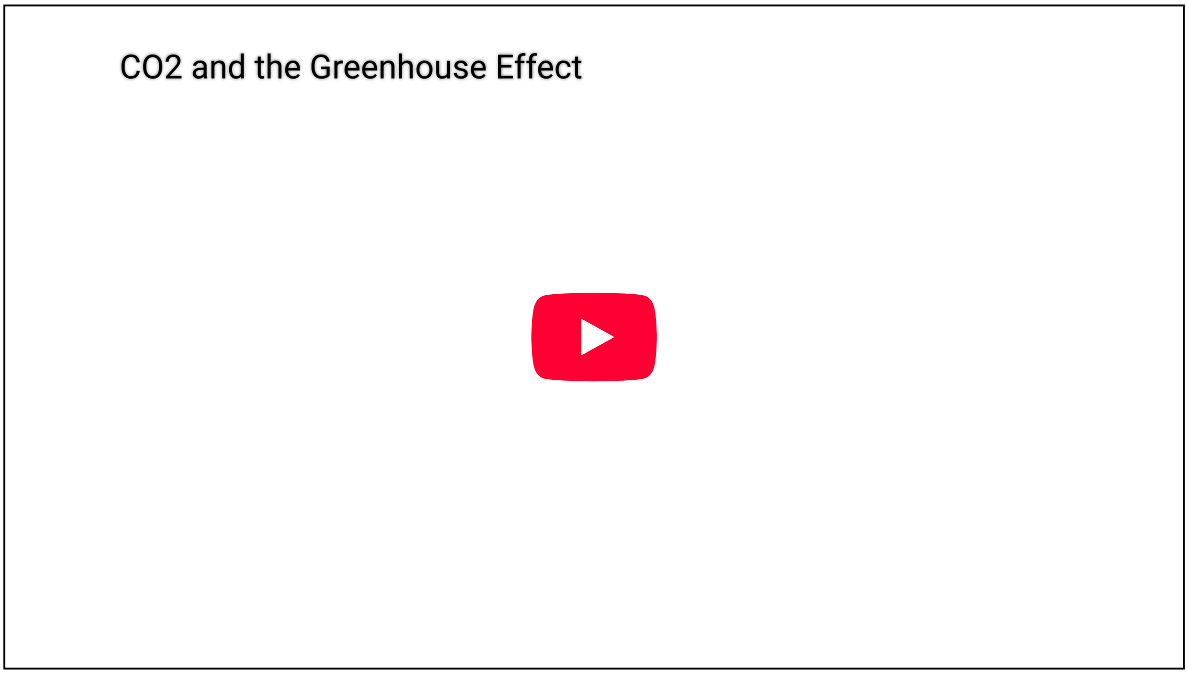
Anthropogenic causes of climate change

Greenhouse gases are gases in the Earth's atmosphere that have the ability to trap heat from the Sun, contributing to what is known as the greenhouse effect. Just like a greenhouse traps heat to create a controlled environment for plant growth, the greenhouse effect in the Earth's atmosphere traps greenhouse gases, leading to the warming of the planet.

This natural phenomenon is crucial for sustaining life on our planet as it helps to maintain a stable temperature. Without these gases, the temperature of Earth would be too cold to support life.

To learn more about the greenhouse effect, watch **Video 1**.

Student
view



Video 1. The greenhouse effect.

The major greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour (H_2O). While water vapour is the most abundant, its concentration is primarily regulated by natural processes such as evaporation and condensation. Human activities, however, have significantly increased the concentrations of carbon dioxide, methane and nitrous oxide.

Increased concentrations of greenhouse gases have led to an enhanced greenhouse effect and subsequent climate change. As we go about our daily lives, we often do not think of how simple daily activities can contribute to significant environmental changes. However, it is important to understand that certain gases released as a result of human activities, known as anthropogenic sources of climate change, play a significant role in altering our planet’s delicate balance.

The increases in atmospheric concentrations of greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4), stand out as a primary concern as anthropogenic activities release substantial amounts of these gases.

Carbon dioxide is released into the atmosphere during cellular respiration by living organisms. In addition, the combustion of fossil fuels (coal, oil and natural gas) results in emission of carbon dioxide, contributing to its accumulation and amplifying the greenhouse effect (**Figure 1**). Deforestation, primarily driven by

Overview
(/study/ap
422-
cid-
755105/o

agricultural expansion and logging, also contributes to increased levels of CO_2 in the atmosphere. Trees and plants play a vital role in absorbing carbon dioxide through photosynthesis, so the reduction of forests reduces the Earth's capacity to remove this greenhouse gas from the atmosphere.

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43218/print/) Assign

Figure 1. Many factories rely on combustion of fossil fuels to operate.

Credit: [Hans Henning Wenk], Getty Images

Methane, another potent greenhouse gas, is released due to various human activities. It is emitted during the extraction of fossil fuels. Agricultural practices, such as livestock farming and rice cultivation, also contribute to methane emissions. Additionally, the decay of organic waste in landfills produces methane, further adding to its atmospheric concentration.

Try the drag and drop activity in **Interactive 1** to test your understanding of anthropogenic sources of greenhouse gases.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Increased CO_2 levels in atmosphere	Increased CH_4 levels in atmosphere

extraction of fossil fuels

combustion of fossil fuels

deforestation

cellular respiration

agricultural practices

decay of organic waste in landfills

Check

Interactive 1. Sources of Carbon Dioxide and Methane.

Interactive 1. Test your knowledge of anthropogenic sources of carbon dioxide and methane.

Nature of Science

- **Aspect:** Patterns and Trends

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Students should be able to distinguish between positive and negative correlation and should also distinguish between correlation and causation. For example, data from Antarctic ice cores show a positive correlation between global temperatures and atmospheric carbon dioxide concentrations over hundreds of thousands of years. This correlation does not prove that carbon dioxide in the atmosphere increases global temperatures, although other evidence confirms the causal link.

The relationship between carbon dioxide (CO_2) levels and temperature increase is often discussed in the context of climate change. It is important to differentiate between correlation and causation when examining this association.

Correlation refers to a statistical connection between two variables. A positive correlation means that as one variable increases, the other variable also tends to increase. Conversely, a negative correlation means that as one variable increases, the other variable tends to decrease.

Long-term data from Antarctic ice cores reveal a positive correlation between CO_2 levels and temperature as shown in the graph in **Figure 2.**

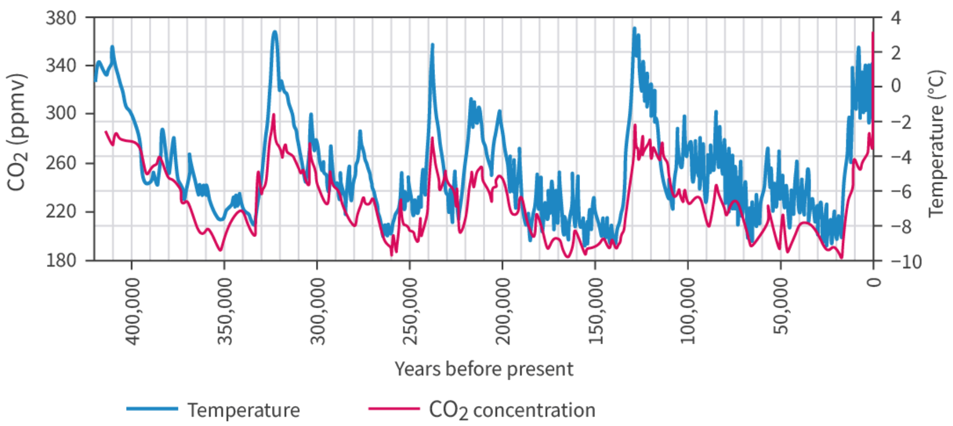


Figure 2. Vostok Antarctica ice core data (420 000 years back from present).

More information for figure 2

The graph presents the long-term Antarctic ice core data, displaying a correlation between atmospheric CO2 concentrations and temperature over a span of 420,000 years.

- **X-axis:** Represents "Years before present," ranging from 400,000 years ago to the present.
- **Y-axis on the left:** Measures CO2 concentration in parts per million by volume (ppmv), with a range from 180 to 380 ppmv.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- **Y-axis on the right:** Indicates temperature variation in degrees Celsius, ranging from -10°C to 4°C.

The graph comprises two colored lines: - A red line represents CO2 concentration. - A blue line indicates temperature changes over time.

Both lines display similar patterns, with noticeable peaks and valleys that align closely. These frequent sharp rises and falls suggest a strong positive correlation between temperature and CO2 levels throughout the recorded timeframe. The dataset illustrates cyclical behavior, with temperature and CO2 levels oscillating together. The closer alignment between the peaks and troughs of both lines visually supports the correlation between atmospheric CO2 concentration and temperature changes over geological time periods.

[Generated by AI]

The graph indicates that over hundreds of thousands of years, whenever there was an increase in global temperatures, the atmospheric CO_2 concentrations were also high, suggesting a positive correlation. However, it is crucial to note that correlation alone does not establish causation.

Causation refers to a cause-and-effect relationship between two variables, where changes in one variable directly lead to changes in the other. Establishing causation requires additional evidence beyond correlation. In the case of CO_2 and temperature, while the positive correlation suggests a relationship, it does not prove that rising CO_2 levels in the atmosphere directly cause increases in global temperatures.

Nonetheless, the causal link between CO_2 and global temperature increases is supported by other evidence. The greenhouse effect, a widely accepted scientific concept, explains how certain gases, including CO_2, trap heat in the Earth's atmosphere and contribute to warming. This understanding is supported by various sources of evidence, such as laboratory experiments, satellite measurements and climate models.

Creativity, activity, service

Strand: Activity
Learning outcome: Demonstrate engagement with issues of global

Student view

Overview
(/study/ap
422-
cid-
755105/o

significance

Climate change awareness campaign

Consider the anthropogenic causes of climate change and raise awareness within your community to take action towards environmental sustainability.

Engage in research and planning to understand the anthropogenic causes and impacts of climate change, then design a creative and informative campaign using media such as posters, social media, presentations, videos or workshops. You could also execute the campaign by organising events, workshops or presentations within your school or local community to spread awareness of how human action impacts climate change.

Once complete, you can evaluate your efforts and reflect on the effectiveness of your campaign.

Positive feedback cycles in global warming

As our Earth experiences the effects of global warming, we encounter feedback cycles that can intensify its effects. These feedback loops, like a series of gears working together, have the power to magnify the warming trend and trigger a cascade of consequences. Here, we will explore examples of how these cycles can amplify the impacts of climate change.

Deep beneath the ocean's surface, a vast reservoir of carbon dioxide is stored in dissolved gases (see subtopic C4.2 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43545/)). However, as temperatures rise due to the greenhouse effect, a process is triggered that leads to the release of this stored CO_2 from the ocean. Warmer temperatures decrease the solubility of CO_2 in water, causing the dissolved CO_2 to escape into the atmosphere. This release of CO_2 from the ocean is known as outgassing. This surge in carbon dioxide levels fuels a relentless cycle, contributing to the ongoing warming trend.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

As global warming takes hold, the snow and ice covering in icy regions like the Arctic starts to melt. This reduction in reflective surfaces means that less solar radiation is reflected back into space and more is absorbed by the Earth's surface. This absorption intensifies the warming, accelerating the melting of snow and ice – a positive feedback cycle that amplifies the effects of global warming. This feedback loop is shown in **Figure 3** (albedo is the proportion of radiation that is reflected by a surface).

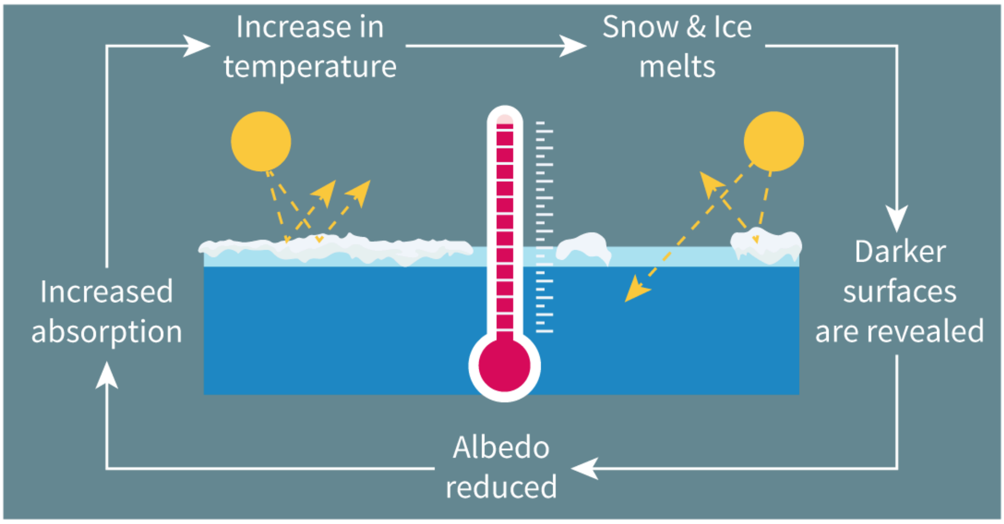


Figure 3. When temperatures increase, this leads to more snow and ice melting, causing darker surfaces to be revealed. This causes albedo — the proportion of radiation that is reflected by a surface — to be reduced and more absorption of light occurs, causing further increase in temperature.

More information for figure 3

The diagram illustrates the albedo feedback loop involving temperature increases, snow and ice melt, and subsequent processes. In the center, a thermometer symbolizes rising temperatures. Arrows show the sequence: increase in temperature leads to snow and ice melting, revealing darker surfaces. This in turn reduces albedo, meaning less radiation is reflected and more sunlight is absorbed, further increasing temperatures. The visual elements include a sun emitting rays, melting ice over a blue surface, and directional arrows indicating the cyclical nature of the process.

[Generated by AI]

Student
view

Overview
(/study/ap
422-
cid-
755105/o

The accelerating rates of decomposition of peat also contribute to increased global temperatures. Peat is a type of organic soil comprising partially decomposed material found in wetland areas, which acts as an important carbon sink or reservoir (**Figure 4**). As temperatures increase, microbial activity in peatlands becomes more active, leading to accelerated decomposition of organic matter. This process releases significant amounts of carbon dioxide and methane, both potent greenhouse gases, into the atmosphere, further increasing the temperature.

Figure 4. Peat.

Credit: Atlantide Phototravel, Getty Images

Another example of positive feedback can be observed in permafrost regions where the ground remains frozen year-round. As temperatures rise, the permafrost begins to thaw, releasing significant amounts of carbon-rich organic matter. This leads to the emission of methane, a potent greenhouse gas, which further strengthens the greenhouse effect, accelerating warming, and triggering more permafrost thawing (**Figure 5**).

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Figure 5. Thawing permafrost.

Credit: SeppFriedhuber, Getty Images

Furthermore, rising temperatures and shifting precipitation patterns contribute to increased droughts in many regions. These droughts, combined with drier conditions, make forests more vulnerable to fires (**Figure 6**). The forest fires release large amounts of carbon dioxide into the atmosphere, further contributing to global warming. The escalation of droughts and forest fires causes a destructive cycle, causing an increase in carbon emissions.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Figure 6. Droughts and high temperatures can trigger forest fires.

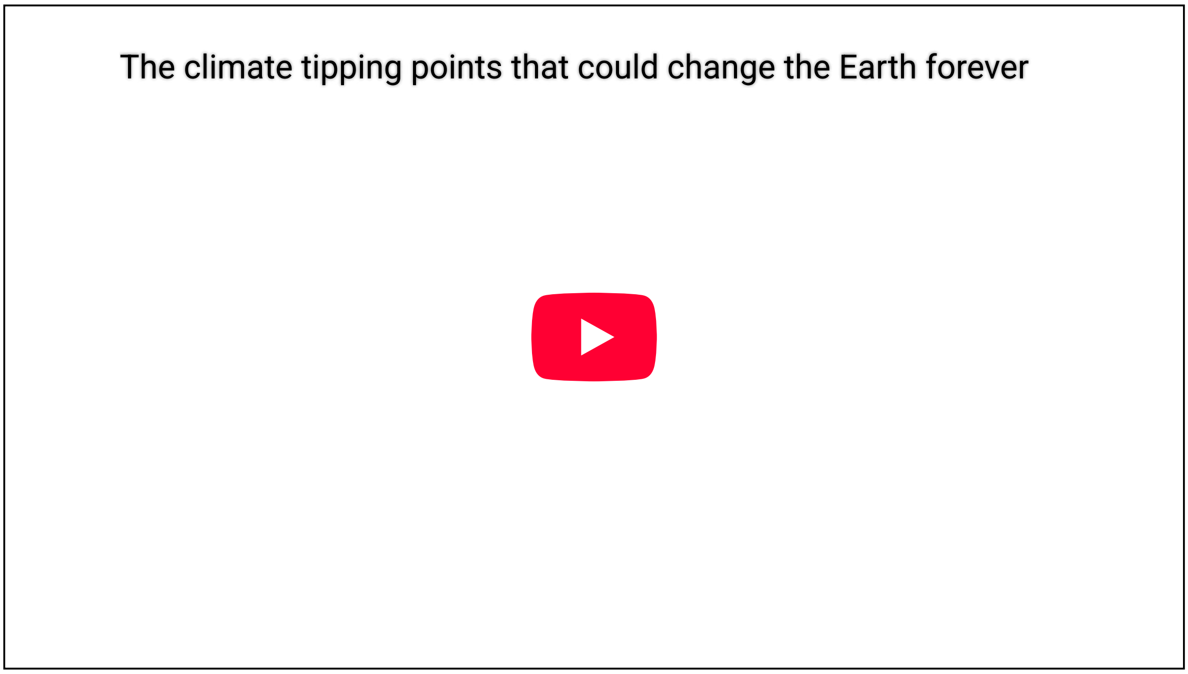
Credit: Bloomberg Creative, Getty Images

Tipping points

The impacts of climate change and rising temperatures have far-reaching consequences for the environment, leading to the emergence of tipping points. A tipping point refers to a critical threshold where a system undergoes significant and potentially irreversible changes due to small disturbances. One compelling instance of a tipping point can be observed in the boreal forests, where the transition from net carbon accumulation to net loss has been observed. Watch **Video 2** to learn more about tipping points (also see section D4.2.1-3 (/study/app/bio/sid-422-cid-755105/book/stability-of-ecosystems-id-44455/)).

Student
view

Overview (/study/ap 422- cid- 755105/o



Video 2. Tipping points and climate change.

The boreal forests, located in the northern hemisphere, encompass vast expanses of dense forests and play a crucial role in absorbing carbon dioxide from the atmosphere to use for the process of photosynthesis. The effects of climate change, including warmer temperatures and reduced winter snowfall, however, have presented significant challenges to this ecosystem. Increased temperatures contribute to greater evaporation and water loss, contributing to drought conditions within the region. As a result, the availability of water decreases, negatively impacting the overall productivity of the boreal forests.

With higher incidence of drought, the primary production of vegetation in the boreal forests is severely affected. The stress on trees and other plant life leads to forest browning, where leaves and needles turn brown and prematurely die off. Additionally, the frequency and intensity of forest fires tend to increase due to the combination of drier conditions and prolonged heat waves, creating favourable conditions for fire ignition and rapid spread (**Figure 7**). In just the first half of 2023, Canada has recorded 3056 wildfires, burning around 20 million acres of land, releasing a whopping 160 million tonnes of carbon into the atmosphere.

Student view

These forest fires not only release substantial amounts of carbon dioxide into the atmosphere but also burn the carbon that has accumulated in the forests over many years, further contributing to carbon emissions.

Overview
(/study/ap
422-
cid-
755105/o

Figure 7. Boreal forest fires can also release deep soil carbon.

Credit: Pierre Longnus, Getty Images

The tipping point that has caused the shift from net carbon accumulation to net loss represents a critical transition in the functioning of these boreal forests (also known as taiga), impacting their role as carbon sinks. Carbon sinks are natural reservoirs that have the ability to absorb carbon dioxide through photosynthesis and help in the accumulation of carbon-rich organic matter in their soils. Climate change has altered the role of these forests and rather than them playing a role in absorbing carbon, through increased incidence of forest fires, they are contributing to the emissions of carbon in the atmosphere.

Polar habitat change

The melting of landfast ice and sea ice serves as a notable illustration of the transformations occurring in polar habitats and the potential repercussions for species dependent on these environments. One such species affected by these changes is the emperor penguin (*Aptenodytes forsteri*), which faces the risk of losing its critical breeding grounds due to the premature breakup of landfast ice in the Antarctic.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Study skills

When you are referring to an organism in an examination, either the common name or the scientific name is acceptable.

For example: emperor penguin, *Aptenodytes forsteri* or *A. forsteri* would be accepted.

When writing scientific names, it is best to underline them.

When typing scientific names, it is best to use italics font.

Figure 8. Emperor penguins (*A. forsteri*) in the Antarctic.

Credit: Johnny Johnson, Getty Images

Landfast ice refers to the ice that remains attached to the coastline during the winter season, providing a stable platform for penguin colonies to breed and raise their young. However, the accelerated melting of landfast ice poses a significant threat, disrupting the emperor penguins' natural breeding cycle and potentially leading to a decline in their population (**Figure 8**).

Student
view

Overview
(/study/ap
422-
cid-
755105/o

In addition to the emperor penguins, the loss of sea ice habitat in the Arctic presents a significant challenge for walruses (*Odobenus rosmarus*) (**Figure 9**). These marine mammals rely on sea ice as resting platforms when searching for food and for migration activities. Unfortunately, the diminishing extent and duration of sea ice in the Arctic, driven by climate change, has created a scarcity of suitable resting areas for walruses. This scarcity disrupts their natural behaviour patterns, forcing them to adapt to less optimal habitats, posing a threat to the walrus population.

Figure 9. The walrus (*O. rosmarus*) population is also impacted negatively by climate change.

Credit: Paul Souders, Getty Images

The melting of landfast ice in the Antarctic and the loss of sea ice in the Arctic exemplify the wider consequences of climate change on polar habitats. These alterations disturb the delicate ecological balance and jeopardise the survival of species that have adapted to these unique environments.

Try the group activity to further explore the topic of climate change.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Activity

- **IB learner profile attribute:** Communicator
- **Approaches to learning:**
  - Research skills — Using search engines and libraries effectively
  - Communication skills — Clearly communicating complex ideas in response to open-ended questions
- **Time required to complete activity:** 90 minutes
- **Activity type:** Group activity

When exploring the topic of climate change as a human right, it is important to understand the contrasting perspectives of the United Nations (UN) and sceptics. The UN has taken a strong stance on climate change, recognising its significant impact on human rights. The organisation has highlighted the need for collective action to mitigate climate change and ensure a sustainable future for all. Through various international agreements and frameworks, such as the Paris Agreement, the UN has emphasised the importance of addressing climate change as a human rights issue.

However, sceptics challenge this perspective and question the link between climate change and human rights. They may argue that climate change is a natural occurrence and that attributing it solely to human activities is an oversimplification. Sceptics may also express concerns about the economic consequences of stringent climate policies, suggesting that focusing on climate change as a human right could divert resources from other pressing social and economic issues.

In this activity, you will participate in a structured in-class debate to explore these differing viewpoints. One group will represent those supporting the United Nations and believe in the negative impacts of climate change while the other group will be the sceptics. To prepare for the debate activity, follow these steps:

1. **Research:** Thoroughly research your respective positions, gathering evidence, statistics and examples to support their arguments. Many diverse reputable sources should be used to strengthen your understanding of the topic.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

2. **Argument development:** Develop clear and concise arguments that support your position. These arguments should be based on factual information and logical reasoning. Aim to anticipate counterarguments to be prepared for potential challenges during the debate.
3. **Evidence gathering:** Gather compelling evidence to support your arguments. This can include scientific studies, reports from international organisations, case studies and real-life examples. The evidence should be credible, up-to-date and relevant to the topic.
4. **Presentation skills:** Practise effective communication and presentation skills, considering how to engage the audience, use persuasive language and present arguments in a clear and organised manner. You can also learn how to effectively respond to questions and counterarguments.
5. **Constructive discussion:** You should engage in respectful and constructive discussions during the debate. It is important to use active listening, acknowledging different viewpoints and responding with evidence-based arguments rather than personal attacks.

5 section questions

D4. Continuity and change: Ecosystems / D4.3 Climate change

Additional causes of climate change and possible solutions

D4.3.5: Ocean current changes D4.3.6: Poleward and upslope range shifts D4.3.7: Potential ecosystem collapse D4.3.8: Carbon sequestration

Learning outcomes

By the end of this section you should be able to:

- Explain the effects of climate change on ocean currents and nutrient distribution.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

- Understand the effect of climate change on range shifts of temperate species and coral reefs.
- Evaluate afforestation, forest regeneration and restoration of peat-forming wetlands as approaches to carbon sequestration.

Section D4.3.1–4 (/study/app/bio/sid-422-cid-755105/book/causes-and-consequences-of-climate-change-id-43578/) details how human activity has contributed to climate change and how global warming has caused negative impacts on forests and polar habitats. However, the impacts of global warming are not limited to these regions. Rather, they are spread worldwide and can impact many other ecosystems and organisms. In this section, you will explore further consequences of climate change.

Changes in ocean currents

Ocean currents are large-scale movements of water in the ocean that are driven by a combination of factors, including wind, temperature, salinity and Earth’s rotation. These currents play a vital role in the Earth’s climate system by distributing heat, nutrients and other properties across the globe. They can be categorised into two types: surface currents, which occur in the uppermost layer of the ocean and are primarily driven by winds and deep ocean currents, which flow beneath the surface and are driven by differences in density.

Climate change has the potential to significantly impact ocean currents. Rising global temperatures can lead to the melting of polar ice caps and glaciers, resulting in the influx of freshwater into the ocean. This influx can alter the density and salinity of seawater, potentially disrupting the natural circulation patterns of ocean currents. Additionally, changes in wind patterns due to climate change can affect the strength and direction of surface currents, further influencing the overall circulation of the oceans. These alterations in ocean currents can have far-reaching consequences, including the redistribution of heat and nutrients, changes in marine ecosystems and impacts on weather patterns and coastal regions.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

To learn more about ocean currents, watch this video (https://education.nationalgeographic.org/resource/ocean-currents-and-climate/).

Nutrient upwelling is the process by which deep, nutrient-rich waters rise to the surface of the ocean (**Figure 1**). It is a crucial mechanism for the supply of essential nutrients, such as nitrogen, phosphorus and iron, to the upper layers of the ocean. Ocean currents play a fundamental role in nutrient upwelling. The timing and extent of nutrient upwelling are influenced by the strength and persistence of ocean currents. Changes in ocean currents, caused by climate change, can impact the occurrence and intensity of upwelling events.

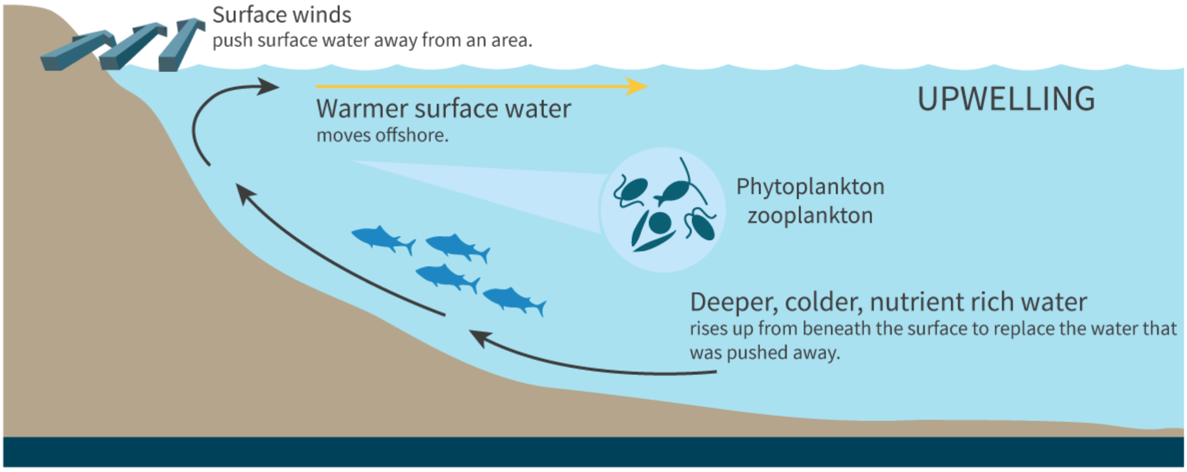


Figure 1. Nutrient upwelling.

More information for figure 1

The diagram illustrates the process of ocean upwelling. It shows warmer surface waters being pushed offshore by surface winds, which are moving from left to right. This causes deeper, colder, nutrient-rich waters to rise up from below to replace the displaced surface waters. The upwelled waters contain phytoplankton and zooplankton, depicted in a circle within the diagram. Overall, the diagram emphasizes the interaction between water layers facilitated by wind action over a coastline, demonstrating the upwelling mechanism.

[Generated by AI]

Student
view

Upwelling can also be wind-driven and can occur when prevailing winds blow along coastlines, pushing surface waters away from the shore and allowing nutrient-rich

Overview
(/study/ap
422-
cid-
755105/o

waters from deeper layers to rise to the surface.

Warmer surface water tends to prevent nutrient upwelling to the surface, decreasing the availability of nutrients to many of the organisms that rely on them. For example, phytoplankton, which are microscopic, photosynthetic organisms that float in the upper layers of the ocean, rely on nutrient upwelling to supply them with nitrogen, phosphorus and iron. Phytoplankton serve as primary producers and form the foundation of the marine food web, providing food and oxygen for a wide range of organisms; therefore, even a small decline in nutrient upwelling may have a drastic effect on marine ecosystems.

Poleward and upslope range shifts of temperate species

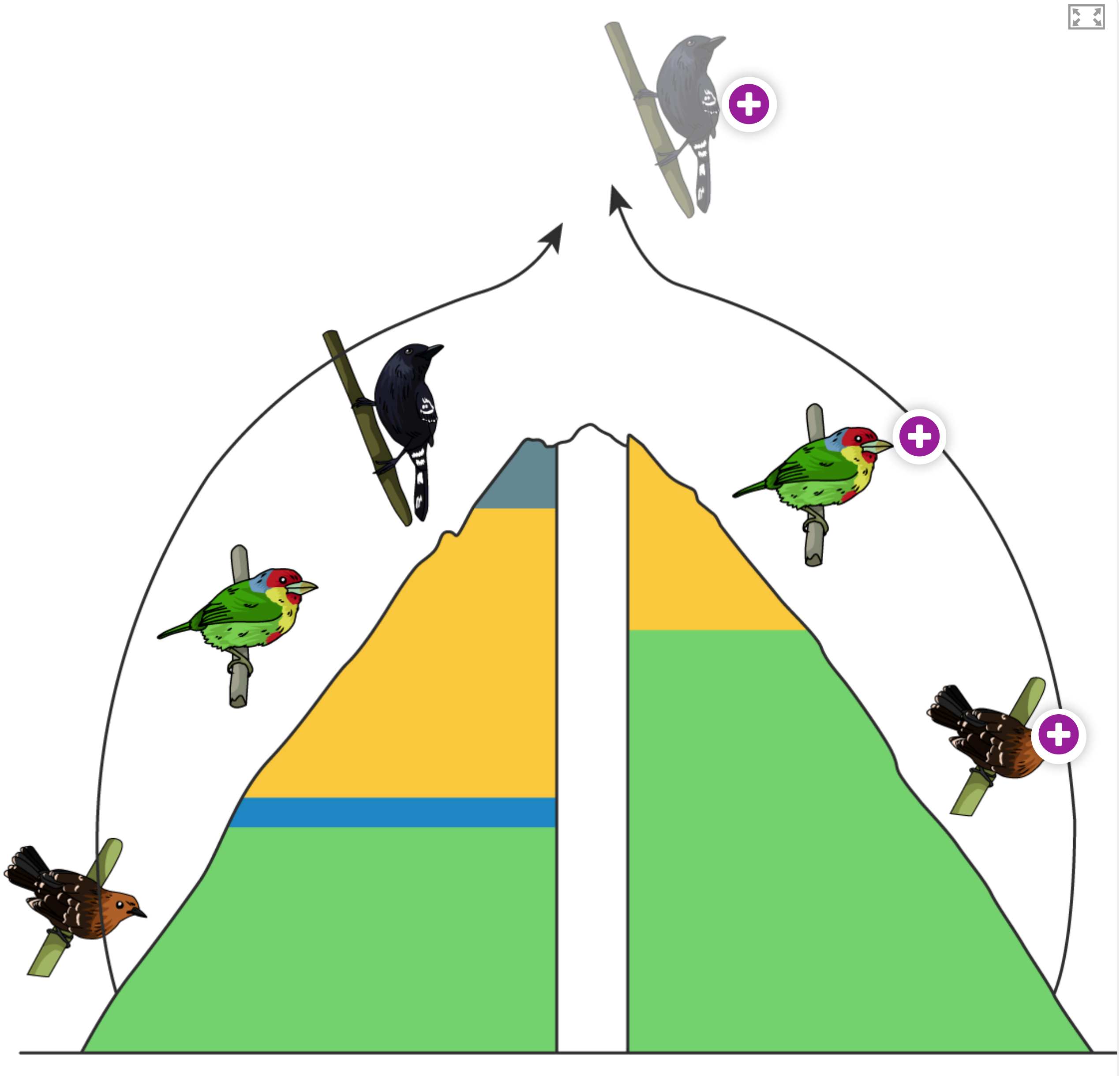
Poleward and upslope range shifts are well-documented phenomena that occur when species gradually shift their distribution towards higher latitudes or elevations. These shifts are often driven by changes in climatic conditions and have significant effects on the biodiversity of ecosystems. Temperate species are organisms that are adapted to inhabiting temperate regions which are characterised by moderate climates with distinct seasons, including mild to warm summers and cool to cold winters. Here are two examples based on scientific evidence that illustrate these range shifts in temperate species.

Upslope range shifts for tropical-zone montane bird species in New Guinea

In the mountainous regions of New Guinea, researchers have observed upslope range shifts in several bird species that are typically found in tropical zones. With the warming climate, these birds have been observed moving to higher elevations in search of more suitable habitats. This response is believed to be driven by the birds' need to find cooler temperatures that resemble their preferred climate conditions. View **Interactive 1** to learn about the upslope range shifts for three species of bird in Peru.

Student
view

Overview
(/study/ap
422-
cid-
755105/o



Interactive 1. The Upward Altitudinal Shift of Three Bird Species on a Mountainous Range in Peru.

More information for interactive 1

The interactive image shows an upslope range shift of three tropical montane bird species in Peru, driven by climate change. The interactive image shows that birds are migrating to higher elevations to track cooler temperatures.

The diagram features a large mountain range in the centre, dividing the landscape into left and right sides. Each side of the mountain has colour-coded elevations. On the left side, the colours in the mountain include green at the base, filled up to a quarter, followed by blue filling a small portion, then yellow filling almost to the top, leaving a small space which is filled with grey. On the right, around 3/4th portion from the base is filled with green while the remaining portion at the top is filled with yellow. Each colour on the mountain likely represents different climate zones, with the bottom being hot and the top being cold. The

Student
view

Overview (/study/app/422-cid-755105/o

left side of the mountain depicts the climate zones before climate change while the right side of the mountain depicts the climate zones after climate change. There are black arrows on both sides to track the shift of the bird's upslope.

There are 3 different bird species, each shown on both sides of the mountain, at different elevations, suggesting different species or populations adapted to those areas. The birds in the interactive are the Common scale-backed Antbird (*Hypocnemis poecilinotus*), The Versicolored Barbet bird (*Eubucco versicolor*), and The variable Antskrike (*Thamnophilus caerlescens*).

The image shows the difference between the suitable climate zones of each bird before and after climate change, explaining the upslope range shift of all three bird species.

There are three hotspots on the right side of the image, one for each bird species. Clicking on these hotspots reveals more information about the bird's upslope shift after climate change.

Read below to learn about each hotspot:

Hotspot 1: This hotspot is located at the top right beside the variable Antskrike bird. This bird looks almost black with a few white specks on the feathers. On the left, the variable Antskrike bird is located in the grey-coloured zone at the top of the mountain before climate change. However, after climate change, on the right side, there is no grey colour zone on the mountain (climate suitable for this bird) and hence the bird image is placed atop and blurred indicating that this bird is not found in the mountains after climate change. Clicking on the hotspot reveals the text “The variable Antskrike (*Thamnophilus caerlescens*) was a mountain-dwelling bird in southern Peru. In 1985, they were present but in 2017, none were detected in the region.”

Hotspot 2: This hotspot is located on the right side for the Versicolored barbet bird near the top of the mountain. It is a colourful bird with green feathers and red, yellow and blue colours near the face and neck region. The Versicolored barbet bird is located in the yellow region on both sides of the mountain. On the left, before climate change, it is located in the middle of the mountain. On the right side, after climate change, the yellow colour zone is at the top and the bird is also situated at the top of the mountain. This indicates the upslope range shift after climate change. Clicking on the hotspot near this bird reveals the text “The Versicolored Barbet birds (*Eubucco versicolor*) moved upslope to retreat from climate change. Birds moving this high upslope are faced with a problem as there is less land area on a mountain at higher elevations providing fewer trees for the birds to inhabit.”

Hotspot 3: This hotspot is located on the right side, near the Common scale-backed Antbird located in the middle of the mountain. It is a brown-coloured bird with black feathers and white spots. This bird is located in the green zone of the mountain on both sides. Before climate change, on the left, the bird is at the bottom of the mountain. However, after climate change, on the right, the bird is located in the middle of the mountain, indicating an upslope range shift after climate change. Clicking on the hotspot near this bird reveals the text “The Common scale-backed Antbird (*Hypocnemis poecilinotus*) moved upslope to retreat

Student view

Overview
(/study/ap
422-
cid-
755105/o

from climate change. Lower elevation birds such as these gained a greater range to inhabit in response to global warming. Bird species that were originally found at lower elevations have expanded their range to occupy habitats that were previously unsuitable due to lower temperatures. As global warming brought milder conditions to these areas, these lower elevation birds gained the opportunity to inhabit new territories that were previously inaccessible."

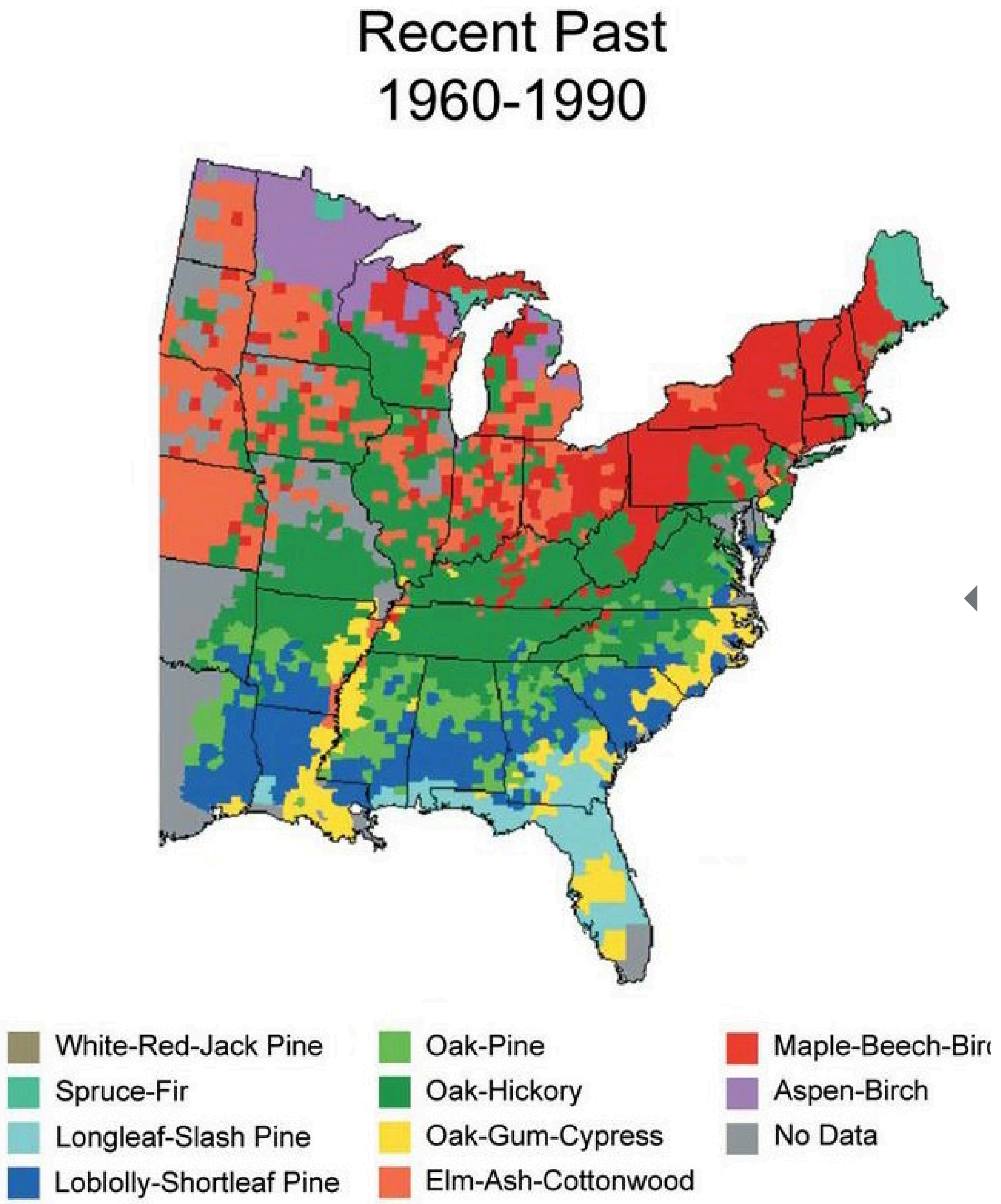
The interactive demonstrates that these shifts are a clear climate change adaptation, and highland species might face extinction as lowland species encroach.

Range contraction and northward spread in North American tree species

Within North America, certain tree species have exhibited range contractions in their southernmost distribution while simultaneously expanding northward. These changes are primarily attributed to shifts in climate conditions. Rising temperatures and altered precipitation patterns have created unfavourable conditions for these tree species in their southern ranges, leading to the contraction of their distribution. Conversely, these same changes have created more favourable conditions for these species in higher latitudes, resulting in a northward expansion of their range. The shifting distribution of these tree species can have ecological consequences, impacting forest composition, carbon sequestration and interactions with other species in the ecosystem. View **Interactive 2** to see the effect of poleward and upslope range contractions of tree species in North America.

Student
view

Overview (/study/ap 422-cid-755105/o



Rights of use

Interactive 2. Effect of Poleward and Upslope Range Contractions of Tree Species in North America.

More information for interactive 2

An interactive with two color-coded maps, depicts projected shifts in forest biome distributions across the eastern United States due to climate change, comparing historical (1960-1990) and future (2070-2100) ranges. The interactive has a slider that can be used to toggle between the two maps for comparison. Both images contain a color-coded legend for tree types at the bottom.

Climate change is driving dramatic redistributions of tree species across North America, characterised by Poleward (Northward) expansion into higher altitudes, Upslope (elevational) migration in mountainous

Student view

Overview
(/study/ap
422-
cid-
755105/o

regions and Southern and low-elevation range contractions.

The first map is labelled "Recent Past (1960-1990)" and shows the baseline distribution of the forest biomes (Spruce-Fir, and Oak-Hickory). It establishes historical ranges before significant climate-driven shifts.

The second map is labelled "Projected (2070-2100)" shows the projected future distributions of the same biomes. It projects that the cold-adapted biomes (Spruce-Fir, and White-Red-Jack pine) are retreating from southern/low-elevation edges and expanding northward into Canadian boreal forests and upward in mountain ranges. Warm-adapted biomes (Oak-Hickory, and Longleaf-Slash Pine) are losing habitats in drought-prone southern regions and are projected to retreat from the south edges because of unsuitable conditions in former ranges. Similarly, tree species (sugar maple, and balsam fir) are retreating from their southern edges due to increased temperatures, drought, and pest outbreaks.

These maps illustrate how climate change is rewriting North America's ecological map, with cascading effects on ecosystems, altering forest composition, biodiversity and societal impacts. Ecological consequences include species trapping, where high elevation trees (Engelmann Spruce) have nowhere to go as mountain tops narrow and mismatched interactions, where bird migrations and pollination cycles may desynchronise with tree flowering.

Theory of Knowledge

To what extent is it possible that social context determines scientific practice? If cultures produce different 'perspectives' or ways to 'be in the world', then a question about whether it is possible for scientific practice to be 'universal' emerges. Can science be produced everywhere in the same way? What factors might produce differences?

Potential ecosystem collapse: threats to coral reefs

Coral reefs, often referred to as the 'rainforests of the sea', are vibrant underwater ecosystems built by tiny coral animals that have skeletons composed of calcium carbonate (**Figure 2**). Due to increases in temperature and carbon dioxide emissions in the atmosphere, coral reefs face numerous threats that can lead to potential ecosystem collapse.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Figure 2. A coral reef in the Pacific Ocean.

Credit: johnandersonphoto, Getty Images

Increased carbon dioxide concentrations in the atmosphere contribute to a process called ocean acidification. As carbon dioxide dissolves in seawater, it forms carbonic acid, leading to a decrease in ocean pH. This acidification hinders the ability of corals to build their calcium carbonate skeletons through a process called calcification. Without proper calcification, corals become more vulnerable to damage and are less able to withstand other stressors.

When carbon dioxide (CO_2) is released into the atmosphere, a significant portion of it is absorbed by the ocean. In seawater, CO_2 reacts with water (H_2O) to form carbonic acid (H_2CO_3) through the following chemical equation:

$$\mathbf{CO_2 + H_2O \rightleftharpoons H_2CO_3}$$

carbon dioxide + water ⇌ carbonic acid

The carbonic acid (H_2CO_3) dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) in the seawater:

$$\mathbf{H_2CO_3 \rightleftharpoons H^+ + HCO_3^-}$$

carbonic acid ⇌ hydrogen ions + bicarbonate ions

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Furthermore, the bicarbonate ions also dissociate into hydrogen and carbonate, increasing H^+ concentrations in the ocean as can be seen in **Figure 3**.

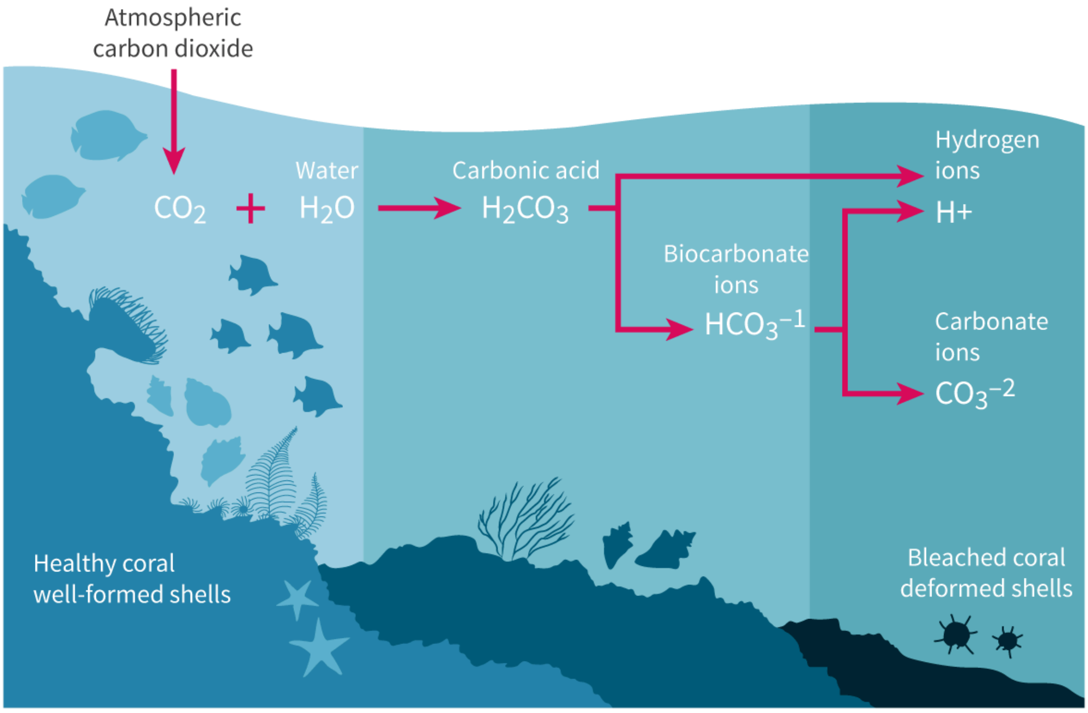


Figure 3. Ocean acidification occurs when more H^+ ions become present, leading to a decreased pH.

More information for figure 3

The diagram illustrates the process of ocean acidification starting with atmospheric carbon dioxide (CO2) dissolving into seawater (H2O). This results in the formation of carbonic acid (H2CO3), which then dissociates into bicarbonate ions (HCO3-) and hydrogen ions (H+). These H+ ions further decrease the pH of the ocean, leading to increased acidity. The bicarbonate ions may also dissociate into carbonate ions (CO3-2), which reduces the availability of carbonate necessary for marine organisms to maintain shells and coral structures. The diagram shows a gradient from healthy coral and well-formed shells on the left, moving to bleached coral and deformed shells on the right as a consequence of these chemical reactions.

[Generated by AI]

The hydrogen ions (H^+) released in this process contribute to an increase in the acidity of the seawater. Acidity is quantified by the pH scale, which measures the

Student
view

Overview
(/study/ap
422-
cid-
755105/o

concentration of hydrogen ions in a solution. As more carbon dioxide dissolves in seawater, the concentration of hydrogen ions increases, causing a decrease in pH and an increase in the acidity of the seawater.

Ocean acidification is a serious concern because it disrupts the delicate chemical balance in marine ecosystems. The increased acidity can interfere with the ability of corals to maintain their skeletons.

Another danger to coral reefs is the rise in water temperature caused by global warming. When ocean temperatures exceed the threshold that corals can tolerate, they undergo a phenomenon known as coral bleaching.

During coral bleaching, corals undergo stress from factors like elevated water temperatures or pollution, which disrupts the mutualistic relationship with the symbiotic algae known as zooxanthellae. As a protective response to the stress, corals expel the algae from their tissues, leading to the loss of vibrant colours typically seen in healthy corals. The expulsion of the algae reduces the production of harmful compounds caused by the coral's excess oxygen, but it also deprives the coral of a vital energy source derived from photosynthesis. Without the algae, the bleached corals become weakened, making them more susceptible to further stressors and potentially leading to their death and the subsequent deterioration of the coral reef ecosystem.

The loss of corals has far-reaching consequences for reef ecosystems. Corals serve as the foundation of these diverse ecosystems, providing habitats, food sources and shelter for a vast array of marine organisms. When corals die, the physical structure of the reef erodes, leaving behind a barren framework as can be seen in **Figure 4**.

Student
view

Figure 4. A coral reef that has been destroyed.

Credit: Brett Monroe Gamer, Getty Images

To learn more about coral reefs and to learn about novel research on ways to help the reef, watch the video on this site (https://edition.cnn.com/2020/02/20/world/coral-reefs-2100-intl-hnk-scli-scn/index.html).

Approaches to carbon sequestration

Carbon sequestration encompasses various approaches and strategies aimed at capturing and storing carbon dioxide (CO_2) from the atmosphere, playing a crucial role in mitigating climate change. Among these approaches, afforestation and the restoration of peat-forming wetlands stand out as effective methods.

Afforestation: this refers to the intentional planting of trees on previously non-forested land (**Figure 5**). This approach is highly effective in sequestering carbon as trees absorb CO_2 during photosynthesis and store it in their biomass. As trees grow, they continue to accumulate carbon, removing CO_2 from the air and storing it in their leaves, trunks and roots. Afforestation projects can be implemented on various scales, from large-scale reforestation efforts to smaller-scale initiatives in urban or degraded areas.

Figure 5. Planting new trees is essential to ensure carbon sequestration in the future.

Credit: okugawa, Getty Images

Restoration of peat-forming wetlands: peat-forming wetlands, including bogs and swamps, have significant carbon storage potential in their waterlogged soils (**Figure 6**). However, human activities such as drainage for agriculture can lead to the release of stored carbon into the atmosphere.

Figure 6. A peat swamp in Indonesia.

Credit: by Alfian Widiantono, Getty Images

The restoration of these wetlands involves re-establishing their waterlogged conditions and preventing further degradation. This restoration process slows down the decomposition of organic matter, allowing the wetlands to act as long-term carbon sinks. Additionally, peatland restoration offers additional benefits such as water regulation, habitat preservation and conservation of biodiversity.

Watch **Video 1** to learn more.

Video 1. Climate change, peatlands and carbon sequestration.

Forest regeneration has two related but different meanings:

- It explains what happens in a forest after a disturbance, such as a windstorm, wildfire, or timber harvest.
- It involves the natural or intentional regeneration of tree cover after forest loss, which can be achieved through planting nursery-grown seedlings after events that have resulted in a forest's partial or total destruction.

Overview (/study/ap 422- cid- 755105/o

Afforestation may be accomplished through natural regeneration, commercial plantations, or agroforestry. The primary difference between afforestation and forest regeneration is that afforestation grows new forests, while forest regeneration regrows current forests.

Nature of Science

Aspect: Global impact of science

Carbon sequestration plays a crucial role in capturing carbon dioxide from the atmosphere. There is an active scientific debate over whether non-native tree species or the rewilding of native tree species should be used for carbon sequestration. Planting non-native, fast-growing tree species can potentially accelerate the carbon sequestration process as they have rapid growth, which means they can absorb more carbon dioxide from the atmosphere in a shorter period. In addition, non-native trees may be more resilient to certain environmental conditions or pests, ensuring a higher survival rate. This approach could lead to faster results in terms of carbon capture, potentially helping to mitigate climate change more quickly.

On the other hand, rewilding the area with native tree species has its own advantages. Native species are already well-adapted to the local ecosystem and have established ecological relationships with other organisms in the area. Reintroducing the native trees promotes biodiversity and ensures the restoration of the ecosystem. So, although native species may not grow as fast as non-native ones, they do contribute to the long-term sustainability of the ecosystem as their presence offers multiple ecological benefits beyond carbon sequestration such as supporting native wildlife.

Another perspective suggests that relying on natural peat formation in waterlogged soils, particularly in temperate and boreal zones, could serve as a viable approach for carbon sequestration. Peatlands are widely acknowledged as highly effective carbon sinks, as carbon gradually accumulates over extensive time periods through the natural process of peat formation. Nevertheless, it is crucial to recognise that in most ecosystems, this process occurs relatively slowly and may not sufficiently address the pressing need for carbon sequestration in the fight against climate change.

Student view

Overview (/study/ap 422- cid- 755105/o

It is worth noting that tropical ecosystems have exhibited the potential for rapid peat formation, emphasising the importance of safeguarding and restoring peatlands in these regions. Nonetheless, it is important to acknowledge that peatlands are often destroyed for agricultural purposes, which can undermine the potential benefits they offer in terms of carbon storage.

Balancing the need for immediate carbon sequestration with the preservation of native species and ecosystems is a complex challenge. An informed and cautious approach needs to be taken to help prevent unintended consequences and ensure that the chosen strategies effectively address the impacts of climate change.

Try the group activity to research some carbon sequestering technologies.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 60 minutes
- **Activity type:** Group activity

Scientists are always looking for ways to better the environment. In addition to afforestation and the restoration of peat-forming wetlands, there are many carbon sequestering technologies and methods that can be used to decrease carbon levels in the atmosphere.

Each group should select one carbon sequestering technology or method from the list below to research and understand its functioning, advantages and limitations.

Possible technologies or methods

- Ocean fertilisation
- Biochar and carbon capture in soil

Student view

Overview
(/study/ap
422-
cid-
755105/o

- Direct Air Capture (DAC) e) Enhanced Weathering
- Carbon capture and storage (CCS)
- Blue carbon (mangroves, salt marshes, and seagrasses)
- Algae-based carbon capture
- Bioenergy with Carbon Capture and Storage (BECCS)
- Soil carbon sequestration through sustainable agricultural practices.

Your task

1. **Information gathering:** collect relevant information about your technology or method including its working principle, potential benefits, limitations, current implementation status and any notable examples or projects.
2. **Presentation and discussion:** present your group's findings to the class, highlighting the key aspects of the chosen technology, and engage in a discussion on the effectiveness, feasibility and ethical considerations associated with the technology.
3. **Evaluation and comparison:** after all presentations, you should collectively analyse and compare the different carbon sequestering technologies.

While preparing your presentation, answer these critical thinking questions:

1. What are the potential environmental benefits and risks associated with each carbon sequestering technology?
2. How feasible and economically viable are these technologies for large-scale deployment?
3. What are the challenges in implementing and regulating these technologies?
4. Are there any ethical considerations regarding the use of these technologies?

5 section questions

Student view

Overview (/study/ap 422- cid- 755105/o

Impacts of climate change on phenology (HL)

D4.3.9: Phenology (HL) D4.3.10: Disruption to the synchrony of phenological events (HL)

D4.3.11: Increases to the number of insect life cycles (HL) D4.3.12: Evolution as a consequence of climate change (HL)

HL Extension

Learning outcomes

By the end of this section you should be able to:

- Define phenology and outline the disruption of phenological events caused by climate change.
- Explain how climate change can lead to increases in the number of insect life cycles.
- Discuss the concept of evolution as a consequence of climate change.

Climate change has drastic effects on the environment and on the delicate balance that is found in ecosystems. In this section, you will explore the consequences of climate change in more detail, learning about specific examples of how changes in climate are impacting organisms. You will also learn about how evolution is a consequence of these changes.

You can optionally watch **Video 1** to get started and learn more about the subject.

Student view

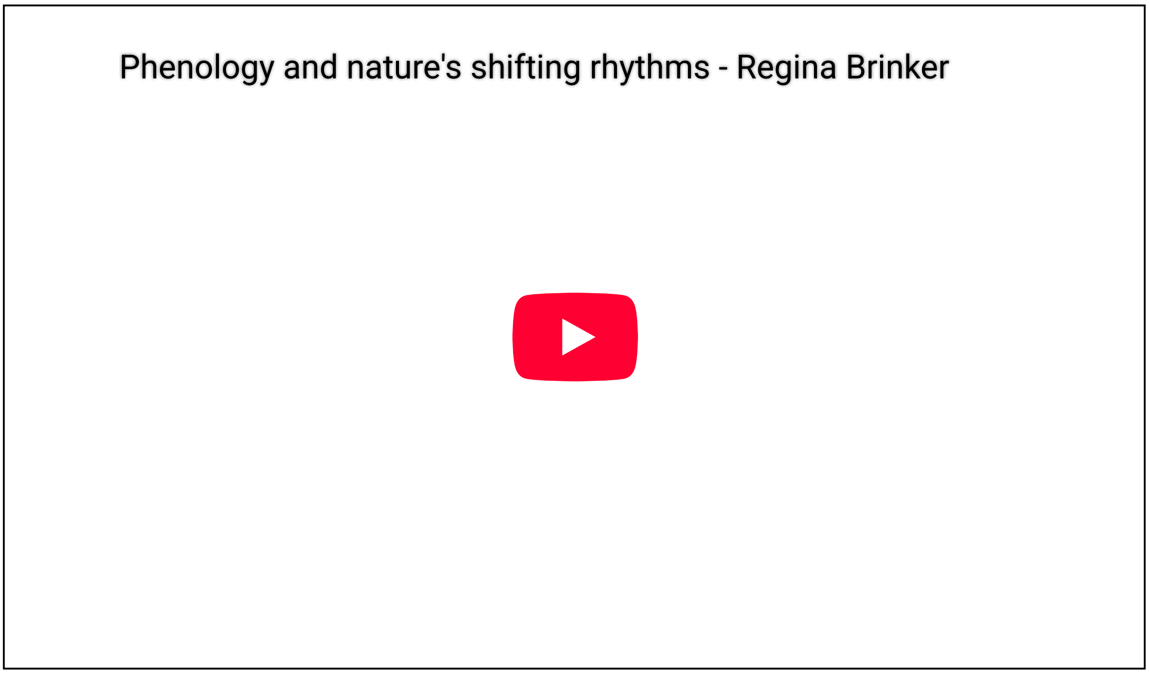
Video 1. Can animals evolve due to climate change?

Phenology and the impact of climate change on phenological events

Phenology is a scientific field that investigates the timing of biological events and their relationship with seasonal and environmental factors. These events include flowering, budburst, bird migration and nesting.

An essential factor that influences these events is photoperiod. Photoperiod refers to the duration of light exposure within a 24-hour cycle and serves as a critical cue for many organisms in determining their life cycle timing. It acts as a signal for seasonal transitions, particularly for species sensitive to changes in day length. For instance, as daylight hours increase in spring, many plant species use this signal to initiate flowering. Phenological events are also influenced by other variables, such as temperature patterns. Temperature directly affects the development and timing of biological events.

Watch **Video 2** about phenology to learn more.



Video 2. Phenology and nature's shifting rhythms.

Budburst, migration and flowering are all phenological events and are discussed in detail below.

Budburst is a phenological event where deciduous trees emerge from winter dormancy as their buds swell, unfold and burst into leaves or flowers, marking the onset of spring (**Figure 1**). In addition to photoperiod, temperature also triggers the process.

Figure 1. Budburst of the Norway maple (*Acer platanoides*) tree.

Flowering is influenced by temperature, photoperiod, light intensity, precipitation and soil conditions. Different plant species have evolved specific mechanisms to sense these cues and initiate flowering at the most favourable time for successful reproduction. Warmer temperatures can accelerate spring growth, leading to earlier flowering in plants.

Overview
(/study/ap
422-
cid-
755105/o

Migration involves the seasonal journeys of different organisms across vast distances in search of suitable breeding grounds and abundant resources. Organisms rely on cues such as photoperiod, temperature and food availability to time their migrations.

Climate change affects phenological events

Climate change disrupts the synchrony of phenological events by altering the environmental cues organisms depend on for timing their life cycles. Here are some examples of how climate change is affecting phenological events.

Arctic mouse-ear chickweed and reindeer

In the Arctic region, climate change affects the spring growth of the Arctic mouse-ear chickweed (*Cerastium arcticum*) and the arrival of migrating reindeer (*Rangifer tarandus*) (**Figure 2**). Rising temperatures may cause the chickweed to initiate growth earlier, while the reindeer's migration timing remains based on photoperiod cues. As a result, the reindeer's arrival may no longer coincide with the availability of the chickweed as a food source. This may impact the reindeer's ability to find food and survive.

Credit: Cocom Oncom / 500px, Getty Images

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Source: "Cerastium arcticum Snöarve 02" (https://commons.wikimedia.org/wiki/File:Cerastium_arcticum_Sn%C3%B6arve_02.jpg

Figure 2. When reindeers (*R. tarandus*) (top) migrate to the Arctic, they rely on chickweed (*C. arcticum*) (bottom) as a source of food.

The great tit and peak biomass of caterpillars

Similarly, in north European forests, climate change can impact the alignment between the breeding of the great tit (*Parus major*) birds and the peak biomass of caterpillars, which are a vital food source for their chicks (**Figure 3**).

Student
view

Overview
(/study/ap
422-
cid-
755105/o

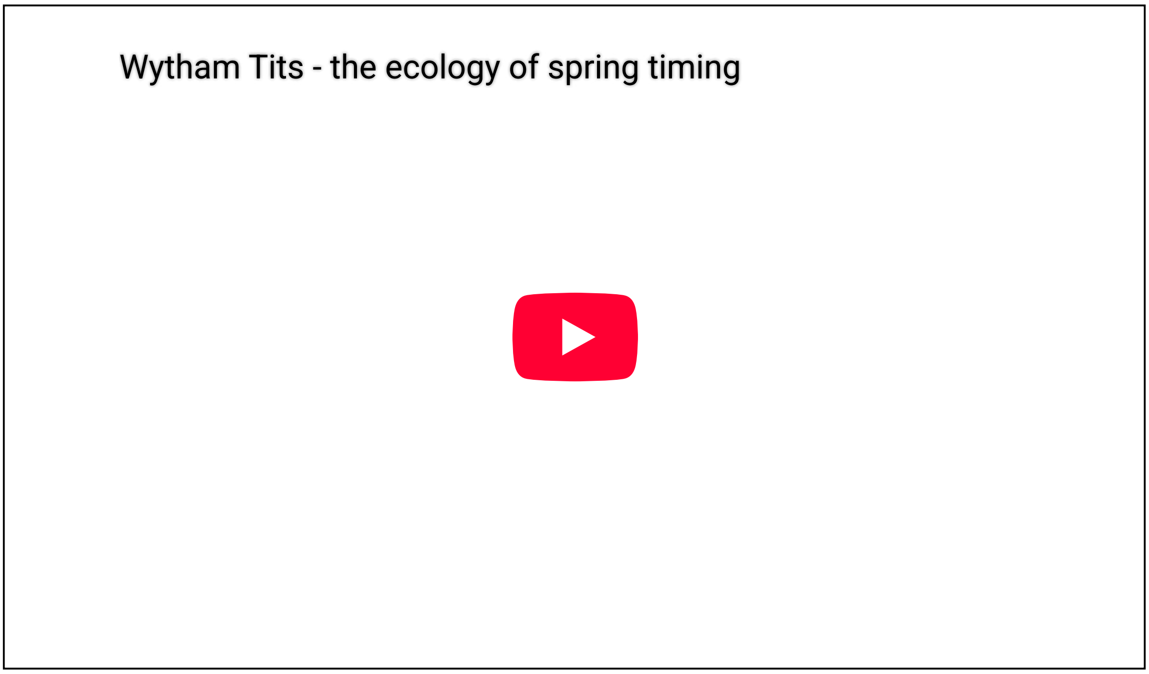
Figure 3. A great tit (*P. major*) carrying a caterpillar back to her nest to feed her chicks.

If warmer temperatures cause the caterpillars to emerge earlier, but the great tits' breeding cycle remains unaffected, a mismatch may occur between chick hatching and the availability of an optimal caterpillar food supply.

The Wytham Tit Project is a long-term population study of the great tits (*P. major*) and blue tits (*Cyanistes caeruleus*) done by the University of Oxford since 1960. Learn more about these birds and the effect of climate change by watching **Video 3**.

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o



Video 3. The Wytham Tit Project.

Climate change causes an increase in insect life cycles

Climate change also has the potential to disrupt ecosystems and alter the life cycles of various insect species. One example is the spruce bark beetle. These beetles are known to infest and damage spruce trees, and their life cycles are directly influenced by temperature and precipitation patterns.

The *Ips typographus* species is one example of the spruce beetle and is native to Europe. An image of the beetle is shown in **Figure 4**.

Student view

Overview
(/study/ap
422-
cid-
755105/o

Figure 4. European spruce bark beetle (*I. typographus*).

Source: "Ips-typographus-02-fws" (https://commons.wikimedia.org/wiki/File:Ips-typographus-02-fws.jpg) by Francisco Welter-Schultes is in the public domain

The acceleration of development and reproduction in spruce bark beetles with rising temperatures can be attributed to their physiological response to environmental changes. As temperatures increase, the metabolic rates of these beetles become more active, leading to faster growth and maturation. This shortened life cycle allows for the potential of more generations to be produced within a single year. Warmer temperatures also stimulate increased feeding and reproductive behaviours in spruce bark beetles, as their metabolic demands rise. This evolutionary adaptation enables the beetles to take advantage of favourable conditions for their survival and reproduction.

In the context of climate change, the rapid growth and population expansion of spruce bark beetles can pose significant challenges for forest ecosystems, as these beetles infest spruce trees, possibly causing their death (**Figure 5**). This can also have cascading effects on other organisms that rely on spruce trees for food or habitat as well. In addition, with more trees dying, they can no longer serve as carbon sinks that are necessary to absorb carbon from the atmosphere.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Figure 5. Norway spruce trees that have been killed by the spruce bark beetle in Northern Austria.

Credit: Walter Geiersperger, Getty Images

International Mindedness

International cooperation is crucial for fostering a global understanding of phenology and climate change. By establishing and maintaining global phenological networks such as the International Coordinated Phenological Observations (ICPO), scientists and researchers from different countries can collaborate to collect and share phenological data. This collaborative effort allows for a more comprehensive understanding of phenological patterns and their responses to climate change across diverse regions and climates.

Evolution as a consequence of climate change

Climate change exerts selective pressures on populations, leading to genetic adaptations and evolutionary changes in response to shifting environmental conditions. These changes can significantly impact the fitness and survival of various organisms (see subtopics A4.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43246/), B4.1 (/study/app/bio/sid-422-cid-755105/book/big-picture-id-43536/), D4.1 (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43238/)). The tawny owl (*Strix aluco*) provides an illustrative example, where alterations in snow cover as a consequence of climate change influence the fitness of different colour variants within the species.

Tawny owls are present in different colours including grey and brown. The colouration of their feathers serves as an adaptation for camouflage within their natural habitats, playing a critical role in their survival and reproductive success. Increasing worldwide temperatures are impacting areas that are usually snow-covered. Regions that usually have snow-fall are now experiencing less snow and for shorter durations.

Student
view

Overview (/study/ap 422- cid- 755105/o

In snow-covered regions, the grey-coloured tawny owl has an adaptive advantage over the brown tawny owl as it can blend in with the white snowy background allowing it to hide from predators (**Figure 6**). With decreasing snowfall, grey coloured owls may no longer have any advantage. In such circumstances, the brown coloured tawny owl, which offers better camouflage in non-snowy or partially snow-covered habitats, may experience enhanced fitness as they can blend in more effectively with tree bark or foliage, providing them with improved concealment and protection.

Figure 6. The brown tawny owl on the right is more adapted to live in areas with no snow cover as it can camouflage with the environment, providing protection from predators. The grey tawny owl (left) is better adapted to survive in snow-covered areas where it can blend in with its surroundings.

Left Credit: Hariyo Adityawarman / 500px, Getty Images; **Right** Source: "Tawny wiki edit1" (https://commons.wikimedia.org/wiki/File:Tawny_wiki_edit1.jpg) by K.-M. Hansche - Edited by: Arad, is licensed under CC BY-SA 2.5 (https://creativecommons.org/licenses/by-sa/2.5/)

Student view

The evolving fitness of tawny owl colour variants in response to changes in snow cover exemplifies the ongoing genetic adaptations driven by climate

Overview
(/study/ap
422-
cid-
755105/o

change. The tawny owls are one example of the many different organisms that are being forced to adapt to their new environment due to climate change.

Try the research activity where you will find out about another relationship between two species influenced by phenological changes brought about by climate change.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Using search engines and libraries effectively
- **Time required to complete activity:** 45 minutes
- **Activity type:** Individual/pair activity

In this subtopic, you have learned about the interconnectedness of different organisms and how some organisms rely on each other for survival.

Your task for this activity is to research another relationship between organisms that may be influenced by phenological changes resulting from climate change.

Possible examples to research:

- polar bears and ringed seals
- coral reefs and coral-dependent fish
- bees and flowers
- Arctic foxes and lemmings
- trees and migratory birds
- butterflies and host plants
- penguins and krill
- forests and fungi.

Choose one of these relationships or another of your choice.

Student
view

Overview
(/study/ap
422-
cid-
755105/o

Make sure to answer the following questions as you are performing your research and be prepared to share your knowledge with your teacher and classmates.

1. How does climate change impact the availability of resources for the organisms in this relationship?
2. What specific phenological changes are occurring due to climate change and how do they affect the organisms involved?
3. How does the disruption of this relationship impact the overall ecosystem in which these organisms reside?
4. Are there any conservation efforts in place to protect this relationship from the impacts of climate change?
5. Can you identify any other species or factors that may indirectly influence this relationship and how they are affected by climate change?

5 section questions

Summary and key terms

- Anthropogenic causes of climate change, such as the increase in greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4), contribute to the enhanced greenhouse effect and subsequent climate change.
- Positive feedback cycles, such as the accelerating decomposition of peat and release of stored carbon from permafrost, intensify global warming by releasing additional greenhouse gases.
- Tipping points, like the transition of boreal forests from net carbon accumulation to net loss, represent critical thresholds where small disturbances lead to significant and potentially irreversible changes in ecosystems.

Student
view

Overview (/study/ap 422- cid- 755105/o

- Changes in polar habitats, including the melting of landfast ice and sea ice, threaten species like emperor penguins and walruses, as they lose their critical breeding and resting grounds.
- Changes in ocean currents, driven by climate change, can disrupt the natural circulation patterns and alter the distribution of heat, nutrients and other properties in the oceans.
- Nutrient upwelling is an essential process for the supply of vital nutrients to the upper layers of the ocean; warmer surface water inhibits nutrient upwelling, reducing the availability of nutrients for organisms like phytoplankton, which are crucial for marine ecosystems.
- Coral reefs face threats such as ocean acidification and rising water temperatures, which can lead to potential ecosystem collapse, affecting the intricate balance and vitality of these diverse underwater ecosystems.
- Carbon sequestration encompasses various approaches and strategies aimed at capturing and storing carbon dioxide (CO_2) from the atmosphere and includes afforestation and restoring peat-forming wetlands.

Higher level (HL)

- Phenology is a scientific field that investigates the timing of biological events and their relationship with seasonal and environmental factors.
- Climate change exerts selective pressures on populations, leading to genetic adaptations and evolutionary changes in response to shifting environmental conditions.

Student view

Overview
(/study/ap
422-
cid-
755105/o

Key terms

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/additional-causes-of-climate-change-and-possible-solutions-id-46663/print/) Assign

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. ______ release substantial amounts of carbon dioxide and methane into the atmosphere.
2. The reduction of forests reduces the Earth's capacity to remove ______ from the atmosphere.
3. The transition of boreal forests from net carbon accumulation to net loss represents a critical threshold in the functioning of these forests as ______.
4. The warming of surface water tends to prevent ______ to the surface, decreasing the availability of nutrients to many of the organisms that rely on them.
5. Climate change can potentially disrupt the natural circulation patterns of ______ by altering the density and salinity of seawater.
6. ______ in temperate species occur when they gradually shift their distribution towards higher elevations or latitudes.
7. Coral reefs face threats such as ______ and ______ as a result of climate change.
8. [HL] ______ is a scientific field that investigates the timing of biological events and their relationship with seasonal and environmental factors.
9. [HL] ______ refers to the duration of light exposure within a 24-hour cycle and serves as a critical cue for many organisms in determining their life cycle timing.
10. [HL] Climate change exerts ______ on populations, leading to genetic adaptations and evolutionary changes in response to shifting environmental conditions.

phenology | coral bleaching | photoperiod | selective pressures | ocean currents | upslope range shifts | carbon sinks | nutrient upwelling | anthropogenic activities | carbon dioxide | ocean acidification

Student view

Check

Interactive 1. Effects of Climate Change.

Checklist

What you should know

After studying this subtopic you should be able to:

- Define anthropogenic climate change and describe its causes.
- Outline the positive feedback cycles in global warming, with examples.
- Describe the transition from net carbon accumulation to net loss in boreal forests as an example of a tipping point.
- Explain the melting of landfast ice and sea ice as examples of polar habitat change.
- Explain the effects of climate change on ocean currents and nutrient distribution.
- Understand the effect of climate change on range shifts of temperate species and coral reefs.
- Evaluate afforestation, forest regeneration and restoration of peat-forming wetlands as approaches to carbon sequestration.

Higher level (HL)

- Define phenology and outline the disruption of phenological events caused by climate change.
- Explain how climate change can lead to increases in the number of insect life cycles.
- Discuss the concept of evolution as a consequence of climate change.

Investigation

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills – Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 45 minutes
- **Activity type:** Individual/pair activity

Your task

Coral reefs are one of the most amazing ecosystems on Earth and have been directly impacted by climate change (**Figure 1**). Coral cover is the percentage of the reef surface that is covered by live hard coral.

Figure 1. Coral reef in Papua New Guinea.

Credit: Georgette Douwma, Getty Images

Overview
(/study/ap
422-
cid-
755105/o

The data in **Figure 2** were obtained from coral reefs near Papua New Guinea during the time period of 1994 to 2004.

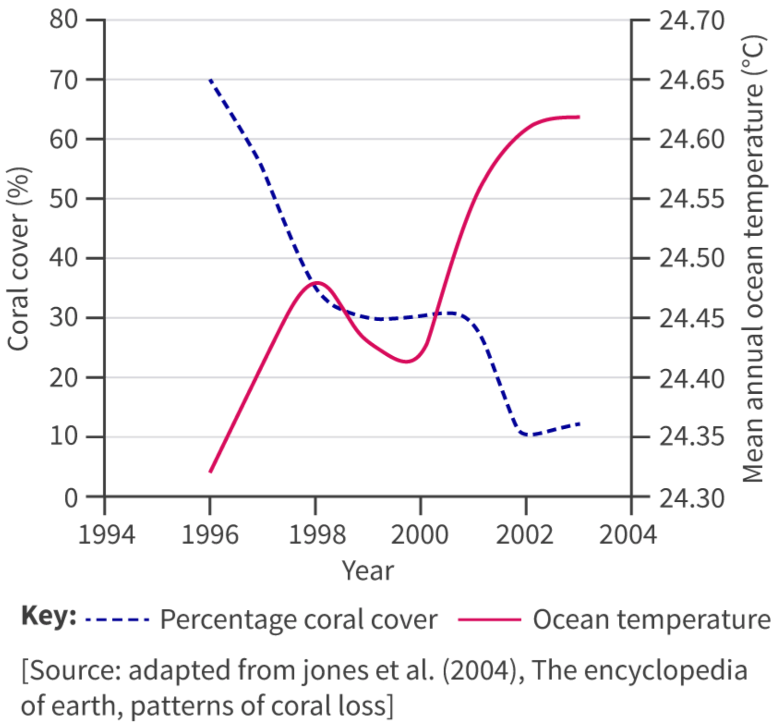


Figure 2. Data from coral reefs near Papua New Guinea during 1994 to 2004.

More information for figure 2

The graph presents data on coral reef conditions near Papua New Guinea over the period from 1994 to 2004. The X-axis represents the years from 1994 to 2004, while the Y-axis on the left represents coral cover percentage ranging from 0% to 80%, and the Y-axis on the right represents the mean annual ocean temperature in degrees Celsius, ranging from 24.30°C to 24.70°C.

Two lines are depicted: 1. A blue dashed line represents the percentage of coral cover which starts at around 70% in 1994, peaking at approximately 60% in 1996, and then declines steeply to below 10% by 2004. 2. A solid red line shows the ocean temperature, starting at about 24.36°C in 1994, fluctuating around 24.40°C between 1996 and 2000, then rising steadily to approximately 24.65°C by 2004.

This graph illustrates an inverse relationship where increasing ocean temperatures correspond with declining coral cover over this decade-long period.

[Generated by AI]

Student
view

Overview
(/study/ap
422-
cid-
755105/o

1. Fill in the following table using data from **Figure 2**.

Year	Coral cover (%)	Mean annual ocean temperature (°C)
1996		
1998		
2000		
2002		
2004		

2. Calculate the difference in coral cover in 1996 and 2002.
3. Describe the evidence that the ocean temperature has an effect on percentage coral cover.
4. Suggest and explain causes for changes in ocean temperatures.

D4. Continuity and change: Ecosystems / D4.3 Climate change

Reflection

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/reflection-id-46901/print/) Assign

Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Student
view

Overview (/study/app/bio/sid-422-cid-755105/o

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.

Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in The big picture (/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43218/).

- What are the drivers of climate change?
- What are the impacts of climate change on ecosystems?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

⚠ Once you submit your response, you won't be able to edit it.

0/2000

Submit

Section Student... (0/0) Feedback Print (/study/app/bio/sid-422-cid-755105/book/impacts-of-phenology-on-climate-change-hl-id-46664/print/) Assign

Student view

Overview
(/study/ap
422-
cid-
755105/o

Rate subtopic D4.3 Climate change

Help us improve the content and user experience.

Student
view