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Climate Change

IB Biology - Revision Notes

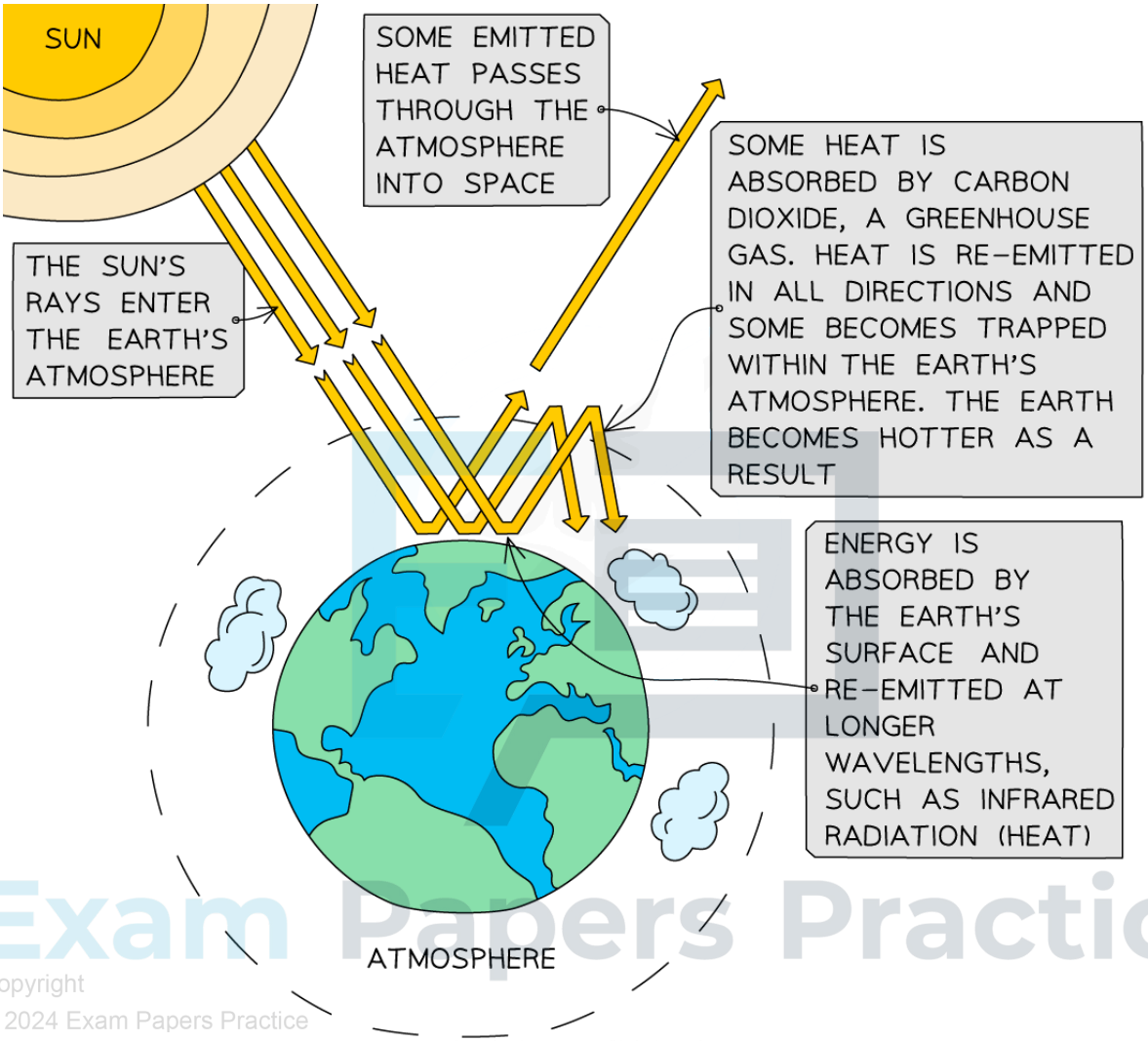
Causes of Climate Change

Climate Change: Anthropogenic Causes

The greenhouse effect

- When **radiation from the sun** hits the earth, it is **radiated back** from the earth's surface
- A **greenhouse gas** is a gas that **absorbs** this re-radiated radiation, **trapping it in the earth's atmosphere** so that it is not lost to space
  - Greenhouse gases in the atmosphere have a similar effect to the glass in a **greenhouse**, hence the term **greenhouse gas**, and their effect being known as the **greenhouse effect**
- The greenhouse effect is important to ensure that Earth is **warm enough for life**; if it were not for the insulating effect of greenhouse gases, Earth would see similar dramatic **temperature fluctuations** to its neighbouring planets
  - Temperatures on Mars range between 20°C and –153°C
- There are many greenhouse gases including
  - **Carbon dioxide**
  - **Methane**
- It is thought that increasing levels of carbon dioxide and methane are entering the atmosphere **as a result of human activities**, leading to increased rates of atmospheric warming
  - The atmospheric warming, and therefore the changing climate, for which humans are thought to be responsible is known as **anthropogenic climate change**

Greenhouse effect diagram



Greenhouse gases absorb radiation re-emitted from the earth's surface, trapping it in the atmosphere

Human activities & carbon dioxide

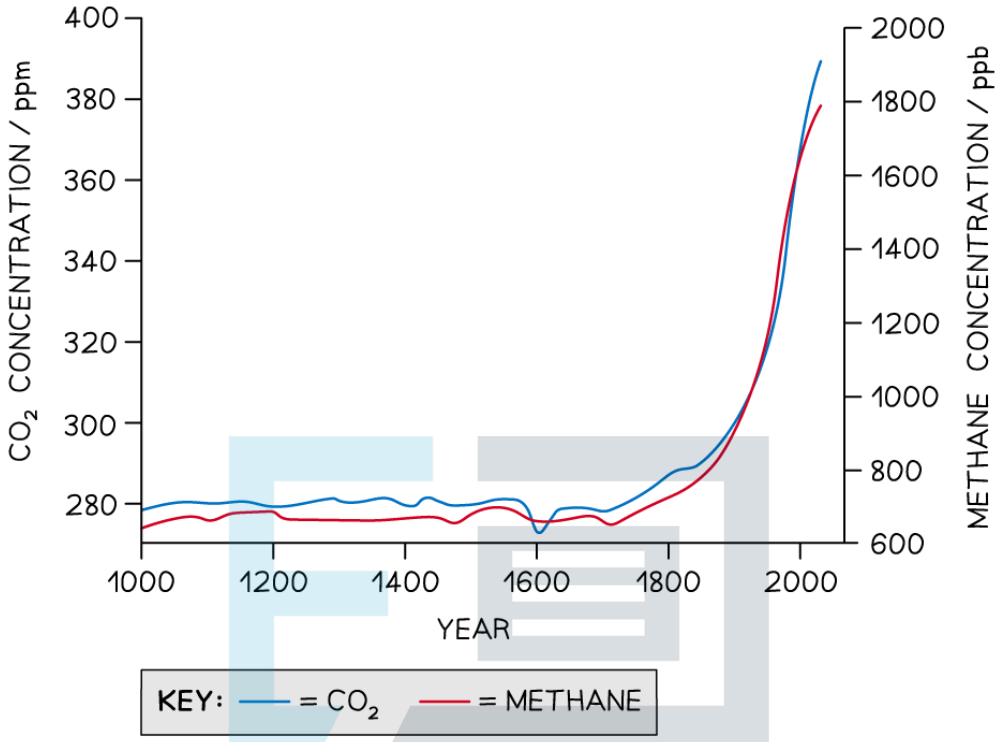
- Atmospheric **carbon dioxide levels** have **fluctuated throughout Earth's history** due to events such as volcanic eruptions and the weathering of limestone rocks
- Since the **industrial revolution**, however, atmospheric carbon dioxide levels have **risen to their highest in Earth's history**
- The industrial revolution began in the late 1700s when the **combustion of fossil fuels** to power **factories, transport**, and **homes** became commonplace
  - Fossil fuel combustion releases **carbon dioxide**

- A clear correlation can be seen between increasing **levels of carbon dioxide since the industrial revolution** and **increasing global temperatures**, providing **evidence** for the role of human activities in causing global warming
  - Note that a **correlation alone is not enough to prove causation**, but this evidence can be taken alongside what we know about greenhouse gases and other evidence to provide a growing body of proof
- In addition to the burning of fossil fuels, carbon dioxide is also released into the atmosphere when **natural stores of carbon are damaged or destroyed** by human activities
  - These carbon stores are known as **carbon sinks**
  - Carbon sinks include trees, soils, peat bogs, and the oceans
    - Deforestation, soil degradation, peat harvesting, and ocean warming all contribute to the addition of carbon dioxide to the atmosphere

Human activities & methane

- **Methane** (CH_4) is a simple **hydrocarbon**
- It is present as a **gas** in the atmosphere, and underground, and is the main component of **natural gas** fossil fuel
- Methane can be produced by **naturally occurring processes** in some types of bacteria, but levels have risen significantly in the last 150 years due to human activities
- Methane can be produced by several human activities
  - Methane is released from the **guts of ruminant mammals** such as cattle
    - While this is clearly not a direct human activity(!) the intensive farming of such animals has greatly increased their contribution to atmospheric methane
  - **Landfill sites** release methane when organic matter such as food waste decomposes
  - **Extraction of fossil fuels from underground** releases methane
  - Anaerobic bacteria in waterlogged **rice paddy fields** release methane
- In addition to the list above, the warming of the poles that results from global warming also leads to the **release of methane from natural stores** such as permafrost
  - Permafrost is ground that remains frozen all year round

Atmospheric carbon dioxide and methane concentration graph

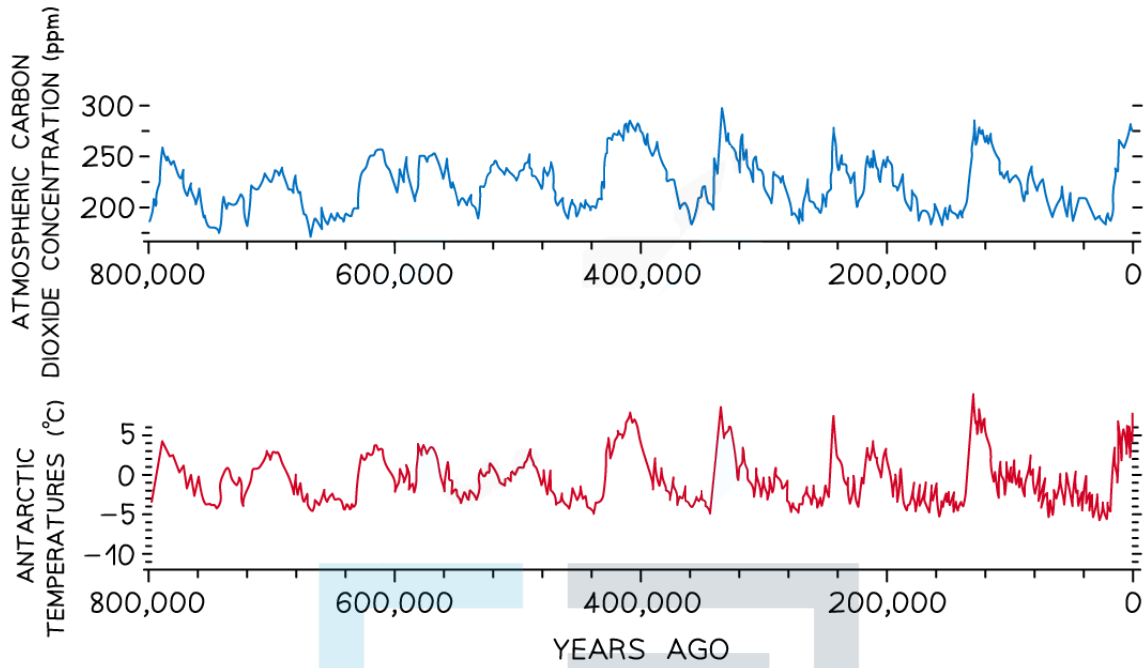


Atmospheric concentrations of both carbon dioxide and methane have increased since the industrial revolution due to human activities. ppm = parts per million and ppb = parts per billion.

NOS: Students should be able to distinguish between positive and negative correlation and should also distinguish between correlation and causation

- **Correlation analysis** involves measuring two variables and **assessing the relationship** between the variables to look for an association
- A relationship that shows correlation can show
  - **Positive correlation** - as one variable increases, the other variable also increases
  - **Negative correlation** - as one variable increases the other variable decreases
- In climate change research, evidence from Antarctic ice cores shows a **positive correlation between global temperatures and atmospheric carbon dioxide** over hundreds of thousands of years

Global temperatures and atmospheric carbon dioxide correlation graph



Evidence from Antarctic ice cores shows a positive correlation between global temperatures and atmospheric carbon dioxide over hundreds of thousands of years

- **While a correlation shows evidence of association**, in itself it does **not provide evidence of causation**, i.e. that a change in one variable has caused a change in the other
  - It is not possible to say which variable has influenced the other
  - It is possible that an unknown third variable might be involved
- Note that in the case of carbon dioxide concentrations and global temperatures, there is **additional evidence** to support a causal link

Exam Tip

Note that the greenhouse effect, global warming and climate change are terms that are often used interchangeably, but the terms have different meanings:

- **Global warming** refers to the rise in global temperatures mainly due to the increasing concentrations of greenhouse gases in the atmosphere
- **Climate change** refers to the increasing changes in the measures of climate over a long period of time – including precipitation, temperature, and wind patterns. These are often a consequence of global warming
- **The greenhouse effect** is a naturally occurring event, constantly occurring due to the atmosphere and sunlight

Global Warming: Positive Feedback Cycles

- Positive feedback is any mechanism in a system that leads to **additional and increased change away from the equilibrium**
- Positive feedback loops occur when **the output of a process feeds back into the system** in a way that moves the system increasingly away from the average state
- In this way, **positive feedback is destabilising**; it **amplifies deviation** from the equilibrium and **drives systems towards a tipping point** where the state of the system suddenly shifts to a new equilibrium

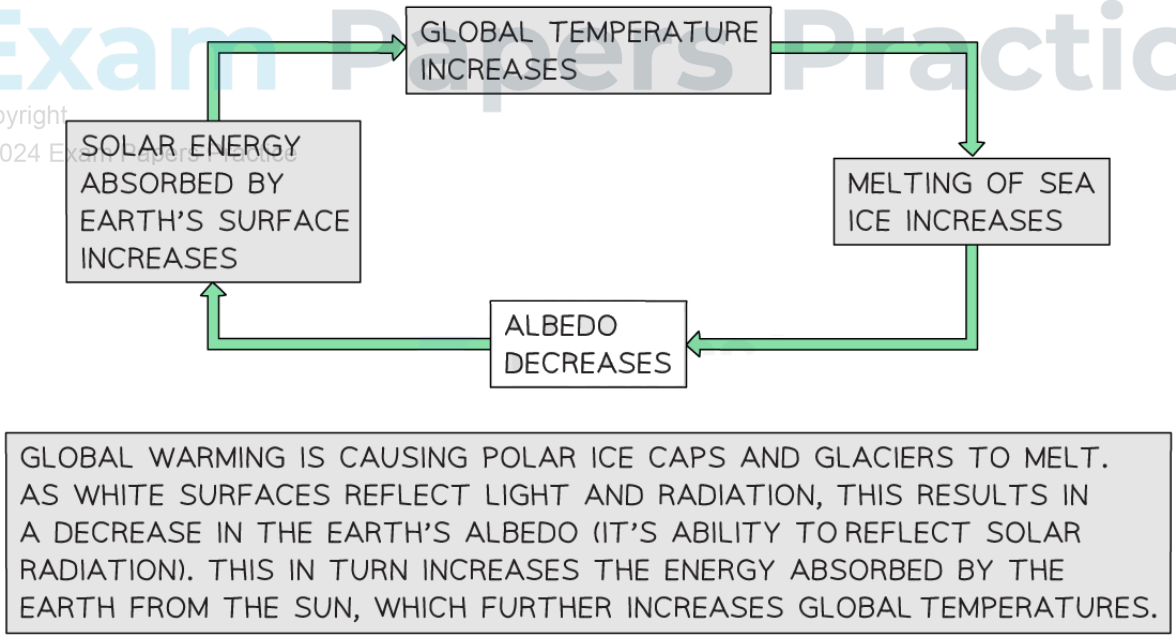
Positive feedback and global warming

- **Global warming has a positive feedback effect** on the earth and its atmosphere
- This means that **global warming leads to more global warming**, which **further increases global warming**, etc.
- There are several factors that contribute to the positive feedback cycle of global warming

Loss of reflective snow and ice

- The extent to which a surface reflects light is known as its **albedo**; the higher the albedo, the more light is reflected
  - Light coloured surfaces such as snow and ice have a high albedo, while dark surfaces such as rock and soil have a low albedo
- **As the polar ice caps melt** due to global warming, the earth's overall albedo decreases, and **more of the sun's energy is absorbed** by exposed rock, soil, and the dark surface of the oceans; this **increases global warming**
  - This cycle continues, further increasing global warming

Impact of melting ice flow diagram



The loss of polar ice contributes to the positive feedback cycle of global warming

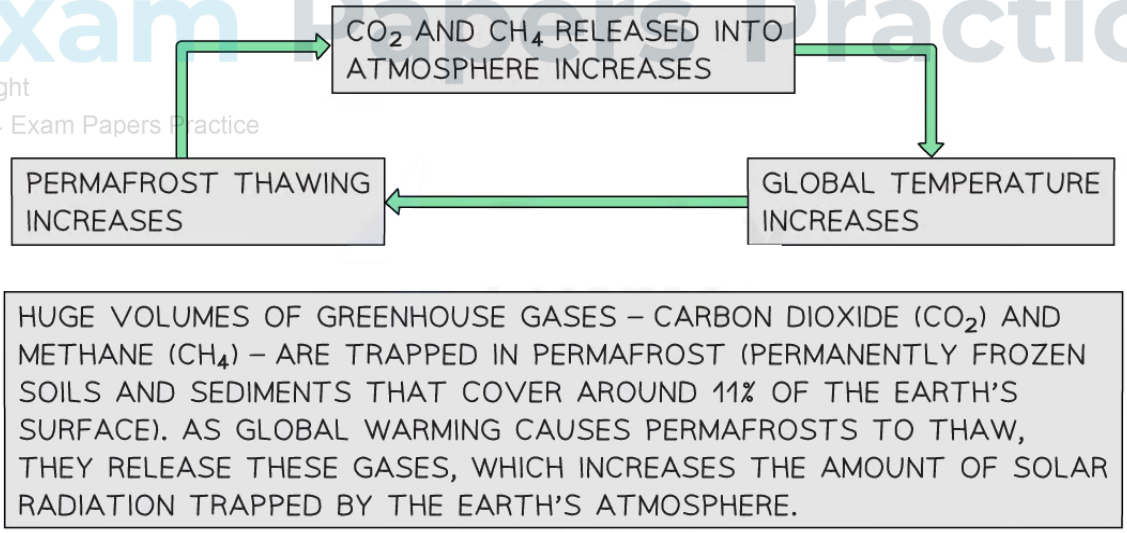
Accelerating decomposition

- Decomposition is carried out by living organisms such as bacteria and fungi
- These organisms break down dead matter and waste in a series of **enzyme-controlled reactions**
- The enzyme-controlled reactions of decomposition occur faster at higher temperatures, meaning that **as global warming increases, rates of decomposition increase**
- The respiration of decay microorganisms **releases carbon dioxide** into the atmosphere
  - Increased **decomposition in peat bogs** releases huge volumes of **carbon dioxide**
    - Peat bogs function as carbon sinks when they are stable
  - Increased **decomposition in permafrost** releases **carbon dioxide**
    - In parts of the world where temperatures remain low all through the year, the ground remains frozen for most of the year; this frozen ground is permafrost
    - Permafrost is a huge **carbon sink** because it contains organic material that cannot decompose at low temperatures
      - Decay organisms are inactive at low temperatures
- Increased atmospheric carbon dioxide further contributes to the greenhouse effect, **increasing global warming**

Release of metha

- Melting permafrost can also lead to the **release of methane** (CH_4), a potent greenhouse gas
- This is due to the **activity of methanogenic microorganisms** in the frozen soil, which **increases as permafrost melts**
  - Methanogenic microorganisms are species of **archaea** that **produce methane** as part of their metabolism

Impact of melting permafrost flow diagram



Melting permafrost leads to the release of carbon dioxide and methane, further increasing global warming

Increasing drought and forest fires

- As global warming increases the frequency of extreme weather events, **droughts occur more often**
- The dry vegetation that results from drought can catch fire easily, and **wild fires become more likely**
- **Combustion** of plant material **releases carbon dioxide** into the atmosphere, where it increases global warming
- The resulting **reduction in the number of photosynthesising plants** means that **less carbon dioxide is removed** from the atmosphere

Impact of Climate Change

Carbon Changes in Boreal Forests

- **Boreal forests**, or **taiga**, form a biome that covers much of North America, Europe, and Russia, and though they have relatively low productivity, these forests are an important carbon sink due to their size
- Boreal forests are at risk of **switching from being a carbon sink to being a** carbon source due to the effects of global warming on their ecosystem processes
  - This switch from sink to source is known as a **tipping point**
  - This further increases the positive feedback effects of global warming
- The reduction in water availability that is caused by global warming is a **huge problem for boreal forests**
  - **Less snow falls** due to increased temperatures, meaning that **less water is available** from snow melt water
  - This leads to **drought**, reducing rates of photosynthesis in the coniferous trees of boreal forests
    - Reduced photosynthesis means **reduced productivity**, and over long periods can kill the trees
      - Lack of water initially leads to a loss of green pigment and a process called **forest browning**, where the trees become brown
      - Eventually the **trees will die**
    - The dead trees dry out and the **risk of forest fires increases**
- The loss of boreal forest **reduces the removal of carbon dioxide** by photosynthesis, and **increases the release of carbon dioxide** by combustion
  - Combustion can **release carbon that has been locked up for many years** in the living trees, dead needles on the ground, and within the soil itself; this is known as **legacy carbon combustion**
  - This can tip the forests from carbon sink to source, and can be irreversible

Polar Habitat Change

- Many species rely on the ice that forms at the poles for their habitat
  - **Sea ice** forms when the ocean freezes
  - Sea ice that is attached to land is known as **landfast** ice
- Global warming means that there is **less sea ice**, and the ice that does form **breaks apart** and **detaches** from the land **earlier in the year** than previously, causing problems for breeding animals
  - **Emperor penguins**, *Aptenodytes forsteri*
    - These birds breed on **Antarctic** sea ice, laying and incubating their eggs, and raising their young
    - The early melting of sea ice is not giving them enough time to raise their young
  - **Walruses**, *Odobenus rosmerus*
    - These mammals rely on **Arctic** sea ice, where mothers can alternate periods of feeding their young and hunting for food in the ocean nearby
    - The early loss of ice means that nursing mothers need to care for their young further from the water's edge, leaving young without protection for longer periods when the mothers hunt for food

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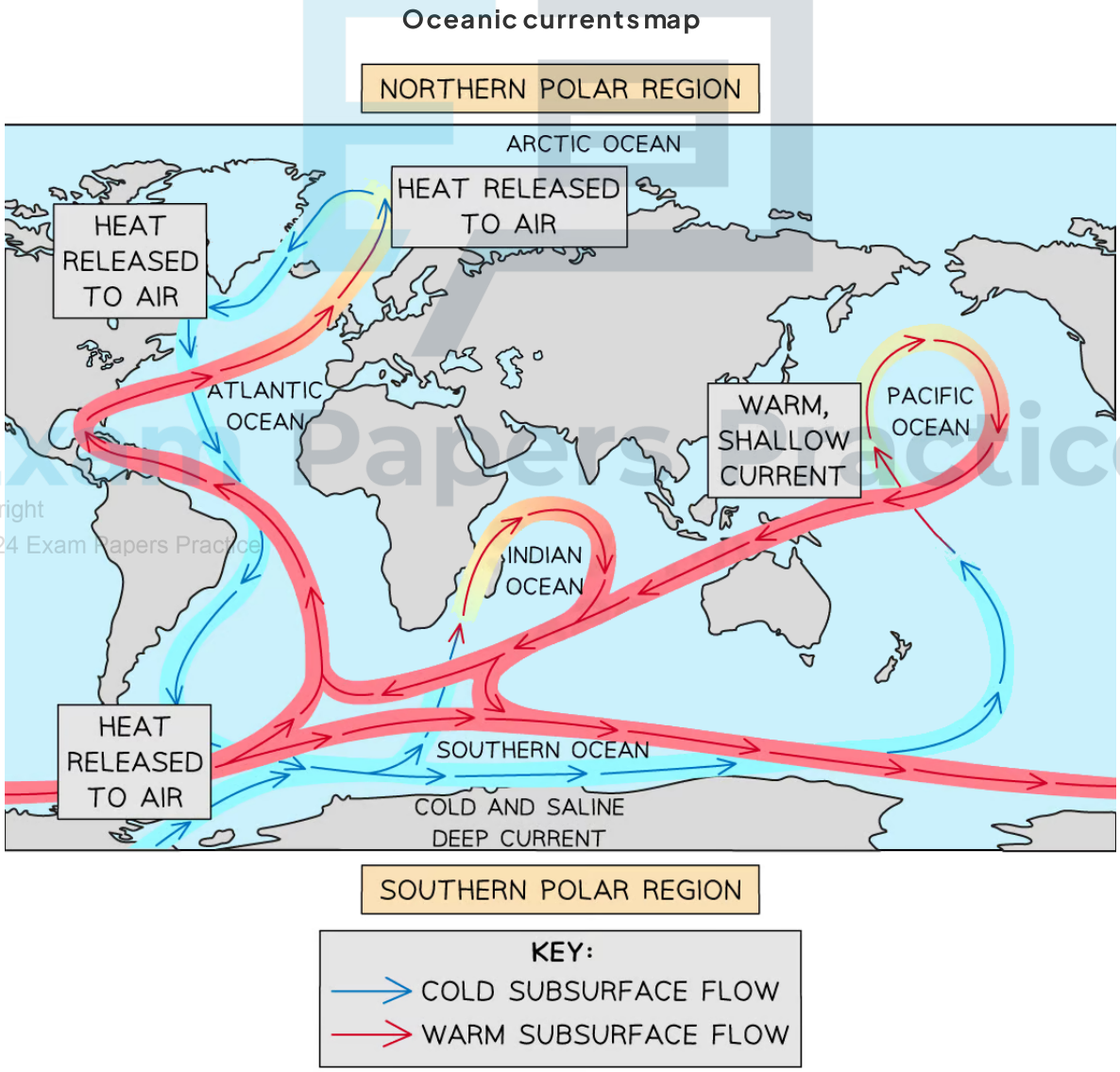
Emperor penguins (left) and walruses (right) rely on sea ice to breed successfully

Exam Tip

Note that, as ever, you will **not** be expected to know the Latin names of species in an exam.

Changes in Ocean Currents

- Weather and climate are strongly influenced by water movement in the oceans, which also play an essential role in **distributing nutrients that support marine life**
- **Ocean currents**, driven by factors like wind, temperature, and salinity gradients, **redistribute heat** across Earth's surface
  - Warm ocean currents carry **heat** from the tropics **towards the poles**, moderating temperatures in coastal areas
    - E.g. the **Gulf Stream**, a warm ocean current in the Atlantic, means that Europe has a warmer climate than Canada, despite being at a similar latitude
  - Cold ocean currents transport **cold water** from polar regions **towards the tropics**, resulting in cooler coastal temperatures and affecting marine ecosystems
- **Upwelling** occurs when cold, nutrient-rich water rises to the **surface**, primarily driven by **wind** that moves surface waters out of the way, allowing deeper waters to rise up to replace them
  - Upwelling brings deep, **nutrient-rich waters to the surface**, supporting abundant marine life and contributing to the productivity of fisheries in coastal areas



Oceanic currents transport heat and nutrients around the world, affecting weather and climate, and influencing marine life

- **Changes in oceanic currents**, such as alterations in current strength or shifts in their paths, **can have significant implications** for regional and global climates, and for **marine life**
- E.g. El Niño events, part of the El Niño-Southern Oscillation (ENSO) cycle, have significant impacts on global weather patterns
  - El Niño events involve the warming of the central Pacific Ocean
  - **Warm surface water prevents nutrient upwelling** in the waters off Central and South America, **reducing primary production** and the **flow of energy** through marine food chains in these regions
  - El Niño can also cause shifts in atmospheric circulation, leading to **droughts, floods, and other extreme weather events**

Range Shifts of Temperate Species

- Species exist **within tolerance limits**, meaning that they can only survive in habitats where the **environmental conditions fall within their** range of tolerance
  - E.g. a marine species may only be able to survive in seawater that falls within certain temperature limits
- Climate change is causing **changes to many local environmental factors**; when this causes the conditions of a habitat to change **beyond what a species can tolerate**, the species must either **migrate** to a new habitat or **face extinction**
- This migration may involve a **shift in** range **distribution** towards the poles, or to a higher altitude, to an area where temperatures are cooler
  - A range shift towards the poles is described as a **poleward shift**
  - A range shift to a higher altitude is an **upslope shift**

Upslope range shifts in montane bird species

- Montane, i.e. mountain-dwelling, species will live at an altitude that suits their needs
  - Altitude affects temperature and oxygen availability, so will influence plant growth and rates of aerobic respiration
- Evidence gathered in the mountains of **Papua New Guinea** over a 50 year period shows that **many bird species have migrated to higher altitudes** over this time period
  - This is **not the case for all species**; a few have stayed in the same place or moved downslope
- E.g. data gathered from Mt Karimui show that bird species have **moved upslope** in this region by an average of more than 100 m

Poleward range shifts in North American tree species

- The northern limit for tree survival is determined by temperature; when **temperatures become too low** for photosynthesis, **no trees will be found**
- Various studies of North American tree species have shown **range contraction**, i.e. the ranges of these trees have shrunk, and **northward spread** for **many species**

Threats to Coral Reefs

- Coral reefs are built from hard **calcium carbonate** deposits that are secreted by organisms called **coral polyps**
  - Note that not all corals build reefs; reefs are built by corals described as **reef-building corals**
- These polyps live in a symbiotic relationship with **algae**, in which the algae provide **carbon compounds** through photosynthesis, and the coral polyp provides **shelter and protection** within its body
- Coral reefs are some of the most **diverse ecosystems** in the world; the complex structures produced by reef-building corals provide habitats for many species, supporting **complex food chains** and providing suitable places to **breed and raise young**
  - Around 25 % of the world's ocean fish species are dependent on coral reefs for survival
- Corals are highly sensitive to factors such as **water temperature** and **pH**, and global warming can have highly damaging effects on the life processes of coral polyps
- **Death of coral polyps** will have a knock-on effect on all other species that rely on the reef, disrupting food webs, reducing the availability of niches and therefore **reducing the reef biodiversity**
  - Many species will die off or migrate to other habitats
  - This leads to **ecosystem collapse**

Ocean acidification & corals

- The impact of increasing carbon dioxide levels on the oceans are **significant for ocean** biodiversity because of the effect of carbon dioxide on **ocean chemistry**
  - Huge amounts of carbon dioxide are **dissolved** by the oceans, and much of the dissolved carbon dioxide **reacts with seawater** to form **carbonic acid** (H_2CO_3)

$$CO_2 + H_2O \rightarrow H_2CO_3$$

  - Carbonic acid then **dissociates** to form **hydrogen ions** (H^+) and **hydrogen carbonate ions** (HCO_3^-)

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

  - Hydrogen carbonate ions can then **dissociate again** to form more hydrogen ions and **carbonate ions** (CO_3^{2-})

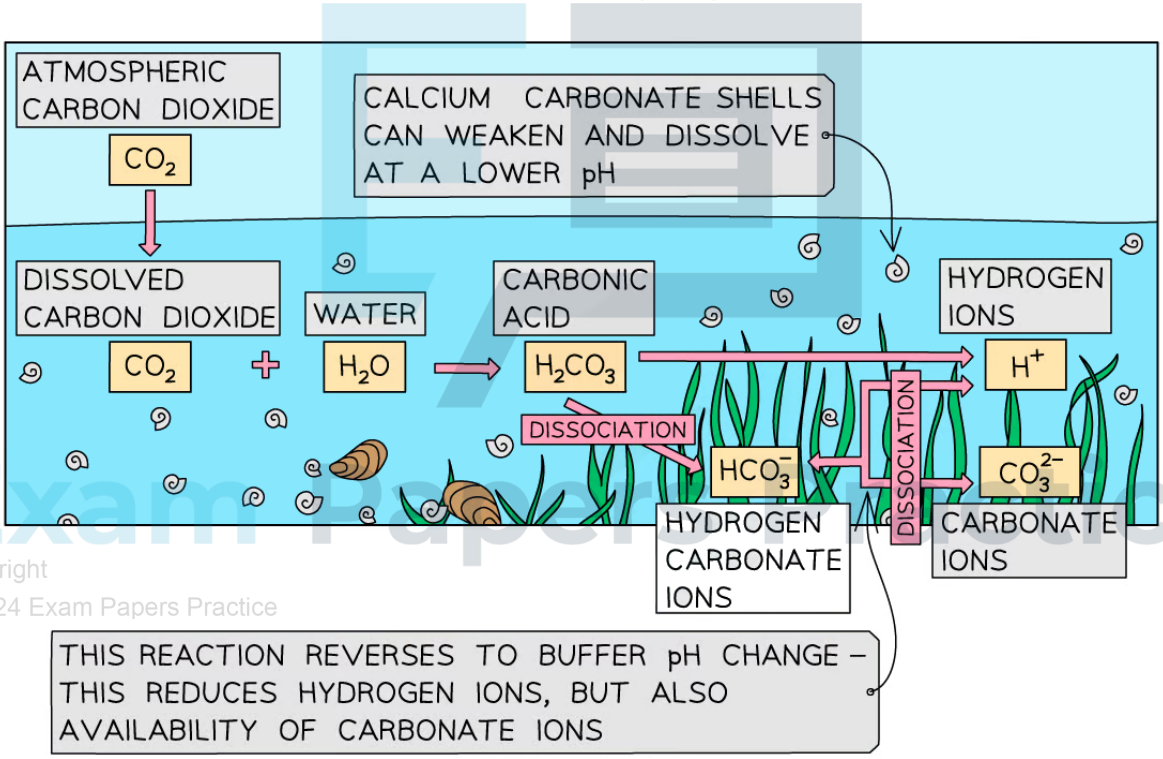
$$HCO_3^- \rightarrow H^+ + CO_3^{2-}$$

- Provided that this series of reactions takes place at the appropriate rate, the oceans remain **slightly alkaline**, and there is a steady supply of **carbonate ions** for organisms that need them
  - Many marine organisms need carbonate ions in order to **secrete calcium carbonate** for the building of the hard parts of their bodies
    - E.g. **reef-building corals** secrete **hard exoskeletons built from calcium carbonate**; these exoskeletons form the complex structures of corals which are a **key part of coral reef** ecosystems

- As atmospheric carbon dioxide levels increase, so too does the **volume of carbon dioxide that dissolves** in the oceans
- As more carbon dioxide dissolves, **more carbonic acid forms and dissociates**, and **more hydrogen carbonate ions form and dissociate**, the end result of which is **increasing numbers of hydrogen ions** in a seawater solution
- Increasing concentrations of hydrogen ions in solution cause that solution to **become more acidic**; in this case the process is known as **ocean acidification**
  - Note that the oceans are **still alkaline**, but the **pH has decreased**, so they are closer to neutral
- There are **significant consequences** to ocean acidification
  - The calcium carbonate exoskeletons of, e.g. corals, can be **weakened** and even **dissolve**
  - The reaction during which hydrogen carbonate ions dissociate to form hydrogen ions and carbonate ions reverses to buffer the increasing number of hydrogen ions, **reducing the availability of carbonate ions** for the building of hard exoskeletons

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

Oceanic chemistry diagram



Increased atmospheric carbon dioxide increases the number of hydrogen ions in seawater, and reduces the availability of carbonate ions

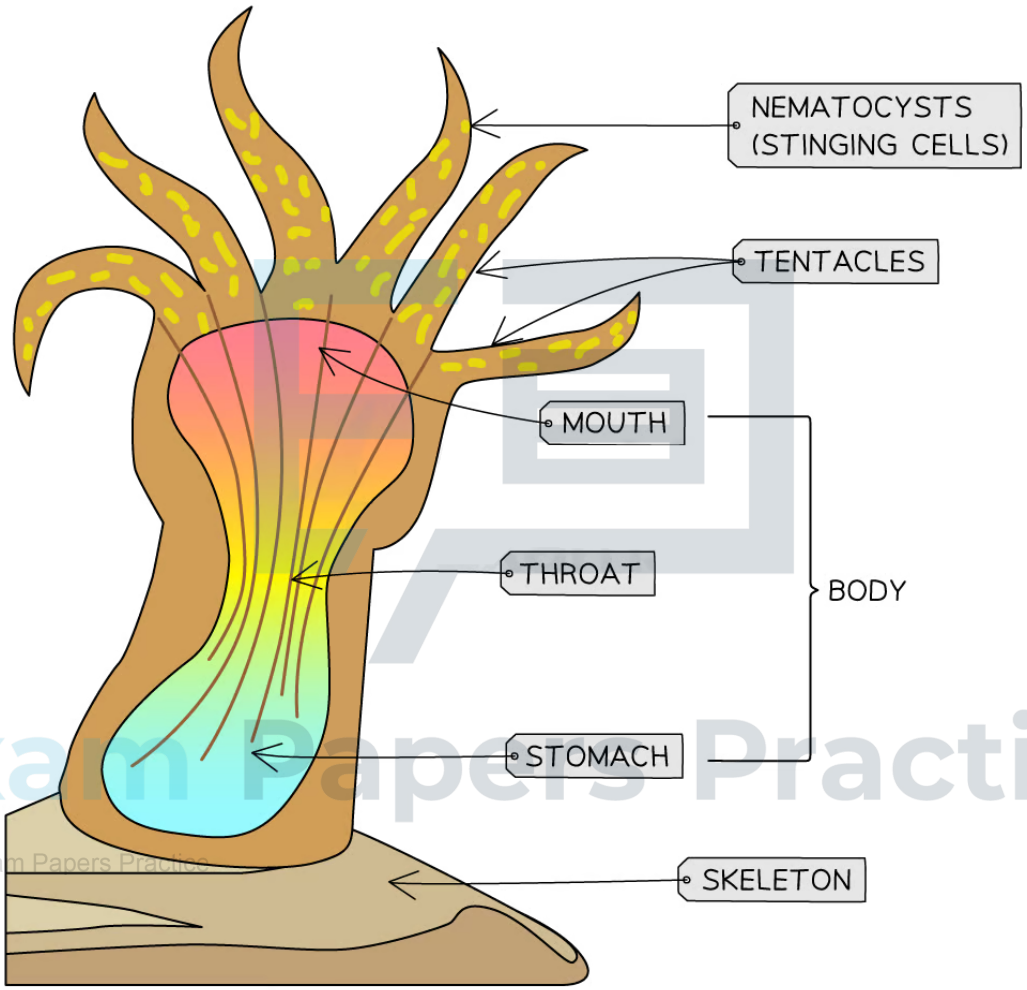
Exam Tip

Note that while ocean acidification shares the same cause as global warming (increased atmospheric carbon dioxide), it is not a direct result of global warming.

Rising ocean temperatures & corals

- High water temperatures cause the coral polyps to **expel their algae symbionts**; this causes the reefs to lose their bright colours and leads to **coral bleaching**
- Because the polyps **rely on the algae for their carbon compounds**, extended bleaching events can lead to the **death of the polyps**

Coral polyp diagram



Rising ocean temperatures cause coral polyps (above) to expel the algae within their tentacles, leading to coral bleaching and eventually death

Carbon Sequestration

Carbon Sequestration

- Scientists believe that global warming can be slowed by **increasing carbon sequestration**
  - Carbon sequestration can be defined as

    The process of capturing and storing carbon dioxide from the atmosphere

- This can be accomplished by increasing the removal of carbon from the atmosphere into natural carbon sinks
  - It is hoped that artificial carbon storage may become viable at some point, but this is still at the research stage
- Natural carbon sequestration can be increased by:
  - **Forest regeneration** and **afforestation**
    - Forest regeneration, or reforestation, involves **planting new trees in deforested areas**, while afforestation is the **creation of new forests**
    - If trees are allowed to grow to maturity, they **can store huge amounts of carbon** in their biomass
      - Some countries around the world have shown that it is possible to restore lost areas of forest by carrying out reforestation, e.g. Costa Rica now plants seven times more trees than it cuts down
      - This kind of achievement requires huge government inputs in the form of benefits to landowners
  - **Peat bog restoration**
    - Peat bogs form when **plant matter cannot decompose** fully due to **waterlogged** (anaerobic) and **acidic** conditions; the carbon stored in the partially decomposed plant matter means that **peat bogs are an essential carbon sink**
      - Peatlands form in boreal and temperate ecosystems, and can form rapidly in tropical ecosystems
    - Human activities include the **harvesting of peat for fuel** and the **draining of peat bogs** to clear land for development and agriculture; these activities release carbon back into the atmosphere by **combustion** or **decomposition**
      - Peat bogs are drained by digging drainage ditches to allow the land to dry out
      - The activity of decay organisms increases as the peat dries out
    - Filling in drainage ditches and regulating peat harvesting can allow peat bogs to recover and to continue growing in depth; this restoration of peat bogs **increases their ability to sequester carbon**

Reforestation (left) and the blocking of drainage ditches on peat bogs (right) can increase carbon sequestration by naturally occurring ecosystem processes

NOS: There is active scientific debate over whether plantations of non-native tree species or rewilding with native species offer the best approach to carbon sequestration

- Scientists **do not always agree** on the best approaches to a process, and different approaches may bring different benefits and problems
- There are differences of opinion among scientists around the best way to approach carbon sequestration by planting trees
  - Some think that **planting non-native trees** which grow quickly and **sequester the maximum mass of carbon** in the shortest time is the best approach
  - Other scientists prefer a **rewilding** approach, which involves **encouraging the growth of native species** and so restores naturally occurring ecosystems; this would sequester carbon more slowly, but could be more beneficial for biodiversity

Climate Change: Phenology (HL)

Phenology

- The impact of climate change can be assessed by studying events that occur in nature
- One field of study that can allow this kind of research is that of **phenology**, which can be defined as

The study of the timing of biological events

- Examples of such biological events include
  - Migration
  - Egg laying
  - Flowering
  - Hibernation

Phenology: deciduous trees

- The effect of environmental factors on the timing of events such as **bud setting**, **bud bursting**, and **flowering** can be studied
  - Bud setting is the process of leaf and flower **bud development**
  - Bud bursting is the process by which **buds unfold**, and results in new leaves and flowers
  - A tree is said to be flowering **when flower buds have burst**
- The timing of the processes described above is crucial to the reproductive success of trees
  - Trees that rely on animal pollinators, such as insects, need to time flowering to coincide with the emergence of their pollinators
  - Trees that use other mechanisms, such as wind or water, may be reliant on the weather, tides, or river volume, which may also be seasonal

Phenology: bird migration & nesting

- Birds **migrate** to different parts of the world at different times of year; this ensures that **temperatures are suitable**, and that they have **enough resources** all year round; it is essential that birds carry out their migration journeys at the right time of year
  - The weather during the migration journey needs to allow birds to reach their new habitat
    - E.g. storms at certain times of year may blow birds off course
  - Birds that migrate too early may find that the environmental conditions are not suitable, or that resources are not yet available, when they reach their destination
  - Birds that migrate too late may find that nesting sites are all taken, or that there are no mates available
- Birds need to **nest** and **lay their eggs** at the right time of year so that chick **hatching** coincides with **resource availability**

- Birds often rely on insect larvae, such as caterpillars, which in turn rely on leaf bud bursting for their food; all of these factors are connected, and contribute to functional food webs

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Events such as bud bursting (left) and chick rearing (right) must happen at the right time of year in order for ecosystems to function

Disruption of Phenological Events

- Climate change can **disrupt the timings of biological events**
  - **Environmental cues** may no longer function as they should, e.g.
    - **Temperature** may be different to previous years
    - Day length, known as **photoperiod**, may not coincide with events that may have occurred in the past
- If events do not occur at the right time, species will be left **without the resources** that they need, and **food chains will be disrupted**
  - Trophic levels may be missing from the food chain
  - This is known as a trophic mismatch

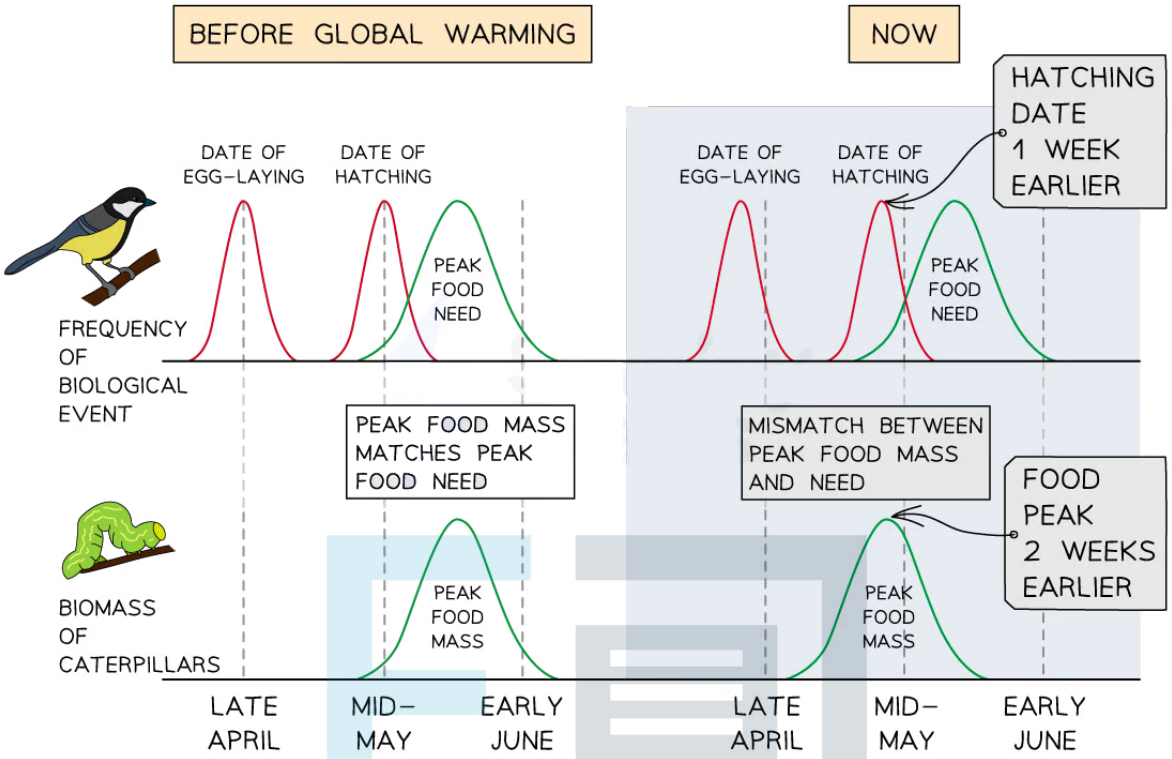
Arctic mouse-ear chickweed & migrating reindeer

- Reindeer are **migratory mammals**, and they rely on **day length** as the environmental cue for seasonal migration
- Arctic mouse-ear chickweed is a plant that forms part of the **diet of reindeer**; its peak productivity is determined by **temperature signals**
- The reindeer migration is unaffected by climate change, but the availability of food that allows them to breed and raise young is affected by climate change; this **mismatch between migration timing and resource availability** can affect the ability of reindeer to breed successfully

Great tits & caterpillars

- Great tits are small birds that often feed on insects; they are especially **dependent on caterpillars** for feeding their young during breeding
  - The great tits need the greatest biomass of caterpillars around 9 days after their chicks hatch
- While both great tit egg hatching and caterpillar availability are **determined by temperature cues**, the **disruptive effect of global warming** on caterpillars appears to be stronger than that on great tits, with **caterpillar biomass peaking around 2 weeks earlier** and **egg hatching peaking around 1 week earlier** as a result of global warming
- This results in a **temporal mismatch** between peak need and peak food availability, reducing the breeding success of the great tits
  - Temporal = related to time

Phenology mismatch diagram



Data from the study of great tit and caterpillar populations shows that global warming has caused a temporal mismatch between peak caterpillar biomass and peak feeding needs of great tit chicks

Effect of Climate Change on Insect Life Cycles

Climate change and the spruce bark beetle

- Spruce bark beetles are insects that **lay their eggs under the bark of spruce trees** and other coniferous tree species; they occur in Europe and North America
- The beetles **feed and mature under the bark** of the trees, **causing damage** and sometimes killing the trees when high numbers of beetle larvae are present
  - Eggs hatch into larvae which **feed from tree phloem and other tissues**
  - Larvae pupate into adult beetles
  - Beetles emerge from the bark and the cycle repeats
- The **life-cycle** of the beetles can occur **once or twice each year**; this is determined by temperature
- Global warming has increased the number of life cycles completed each year; **higher temperatures mean that two life cycles are more likely to occur**
- This increases the size of the beetle population and means that trees are subject to the damaging larvae twice each year; this increases the chance of tree death

Spruce bark beetles can kill trees, partially or completely killing areas of coniferous forest; global warming makes tree death more likely

Exam Tip

Remember that Latin names of species are **not** required in exams

Climate Change: Evolution (HL)

Climate Change: Evolution

- **Natural selection** is driven by **selection pressures** in the environment
  - Selection pressures are **features of the environment that limit the survival chances** of an individual, e.g. the presence of a predator, a lack of food, or antibiotics killing bacteria
- Climate change introduces **new selection pressures**, so can drive evolution by natural selection

Evolution in tawny owls

- Tawny owls show polymorphism, meaning that their alleles can give rise to different phenotypes, or morphs
  - E.g. some tawny owls are **grey** in colour, while some are **brown**
- A decades-long Finnish study has shown an **increase in the frequency of brown owls** in the population from around 30 % to around 50 %; this is thought the be due to natural selection
  - In a snowy environment, pale grey owls are less visible, so are more successful and have a better chance of surviving and reproducing
    - It is not known whether decreased visibility is relevant to increased success in catching prey or increased success in avoiding predators, or both
  - Global warming and milder winters mean that there is less snow, and **owls that are brown in colour have increased success**; these brown owls are more likely to survive, reproduce and pass on their alleles for brown feathers

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Tawny owls show colour variation; milder winters caused by global warming give a selective advantage to owls with brown feathers, which are increasing in frequency