



Climate change

Revision notes · IB Biology climate change: CO₂ and methane, positive feedback, tipping points, polar ice, coral reefs, range shifts and phenology (HL).

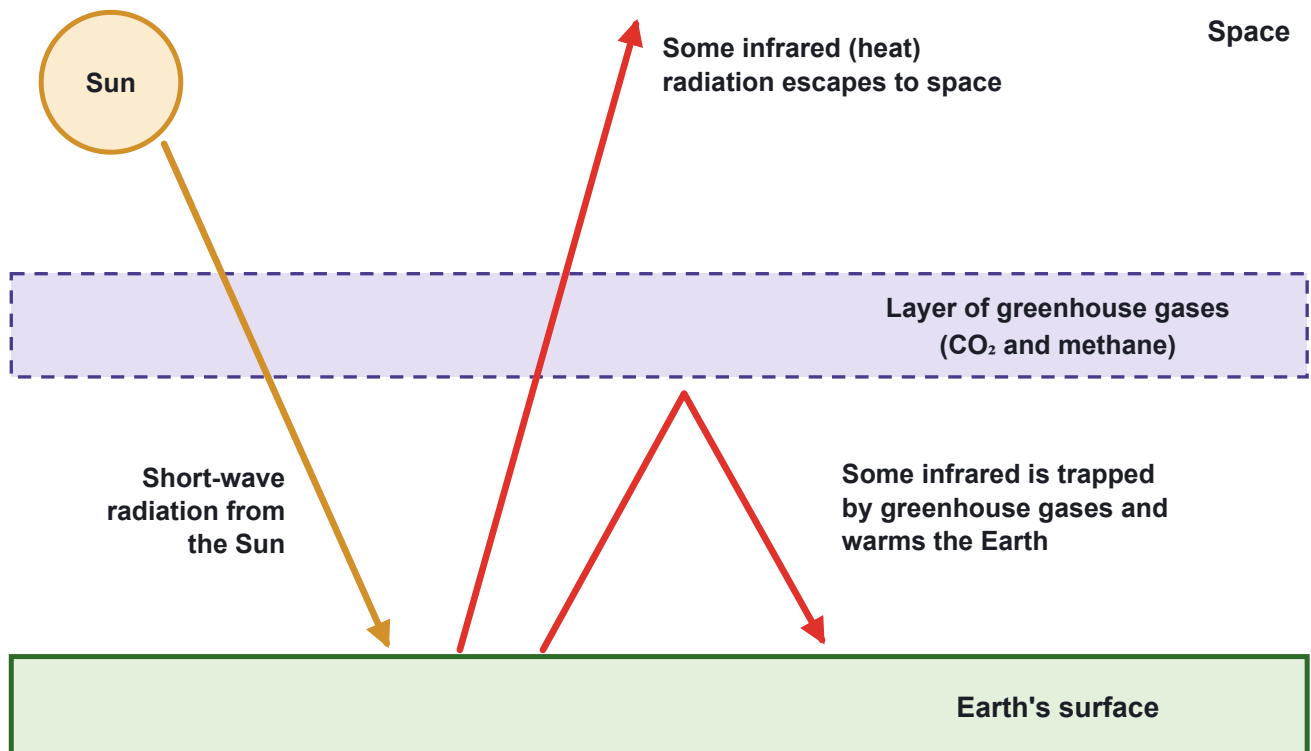
For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Climate change Spec D4.3

Anthropogenic causes and positive feedback Spec D4.3.1, D4.3.2

Carbon dioxide and methane are greenhouse gases: they absorb and re-emit longer-wave infrared radiation from the Earth's surface, warming the atmosphere. **Anthropogenic** (human-caused) increases in their concentrations enhance the greenhouse effect.

Gas	Main anthropogenic sources
Carbon dioxide	Combustion of coal, oil and natural gas; deforestation and burning of forests; cement production
Methane	Livestock such as cattle (fermentation in the gut); flooded rice fields; landfill; leaks from fossil fuel extraction



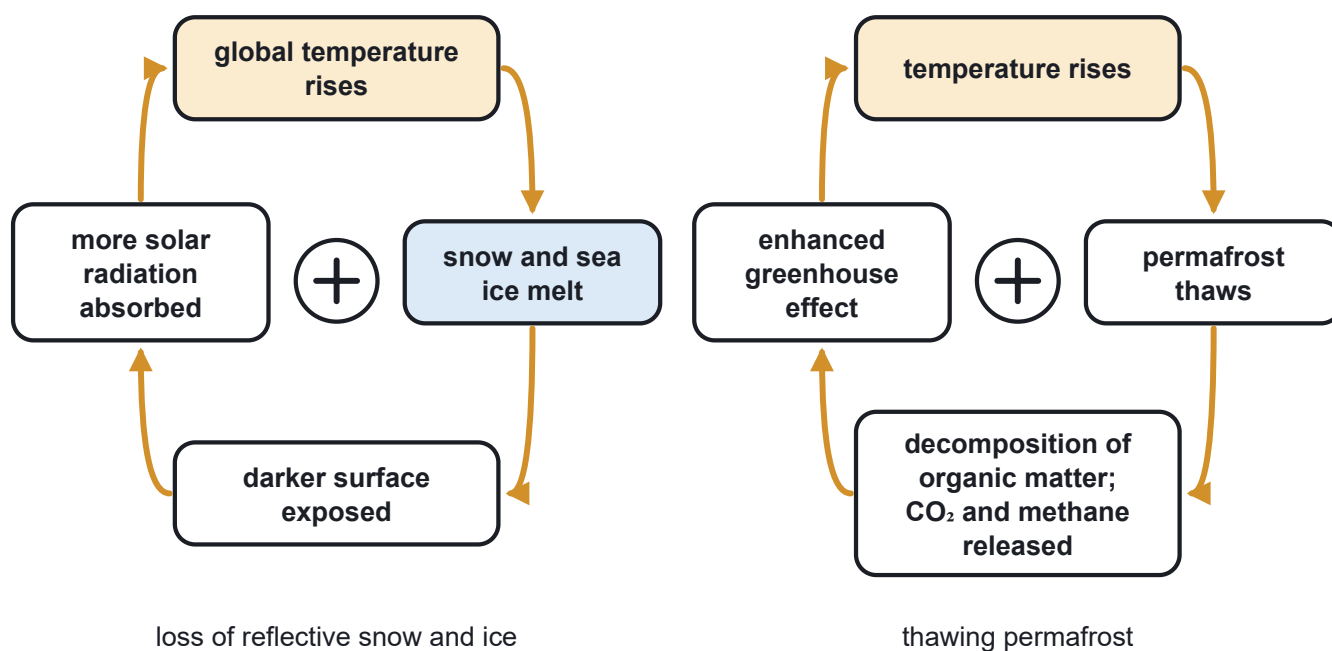
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Increased CO₂ and methane trap more **infrared radiation**, warming the Earth.

Positive feedback cycles

In **positive feedback**, warming causes changes that cause further warming.

- **Release of CO₂ from the deep ocean:** warmer water holds less dissolved CO₂, and changing circulation brings CO₂-rich deep water to the surface, where it is released.
- **Loss of reflective snow and ice:** dark land and sea absorb more solar radiation than white ice, so warming speeds up.
- **Decomposition of peat and permafrost:** thawing allows faster decomposition of peat and of previously undecomposed organic matter, releasing CO₂.
- **Methane from melting permafrost:** anaerobic decomposition in waterlogged thawed soil releases methane.
- **Droughts and forest fires:** fires release CO₂, and drought-stressed plants absorb less CO₂.



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Two **positive feedback** cycles: loss of reflective ice and thawing permafrost both speed up warming.

Boreal forest tipping point and polar habitat change Spec D4.3.3, D4.3.4

Boreal forests: from carbon sink to carbon source

Boreal forest (taiga) covers much of Canada, Scandinavia and Russia. It has stored huge amounts of carbon in trees and deep soil layers, accumulating more carbon each year than it loses. Climate change could switch it to **net carbon loss**, an example of a tipping point.

1. Warmer temperatures and decreased winter snowfall mean less meltwater in spring.
2. Drought becomes more frequent, so primary production in the taiga falls.
3. Stressed trees lose needles and die: **forest browning**.
4. Forest fires become more frequent and intense.
5. Fires burn **legacy carbon**: old organic matter in deep soil layers that survived earlier, less intense fires.
6. The forest releases more carbon than it absorbs.

Melting of landfast ice and sea ice

Landfast ice is sea ice attached to the coast. **Emperor penguins** (*Aptenodytes forsteri*) breed on it in the Antarctic winter, and chicks need stable ice until they grow waterproof feathers. Early breakout of

the ice drowns or chills chicks, so breeding grounds can be lost. In 2022, several colonies in the Bellingshausen Sea region lost almost all their chicks this way.

Walruses in the Arctic use floating sea ice as a platform for resting and nursing calves between dives to feed on shellfish on the shallow sea bed. As sea ice retreats, walruses crowd onto beaches in very large groups, where calves can be crushed in stampedes, and must swim further to feed.

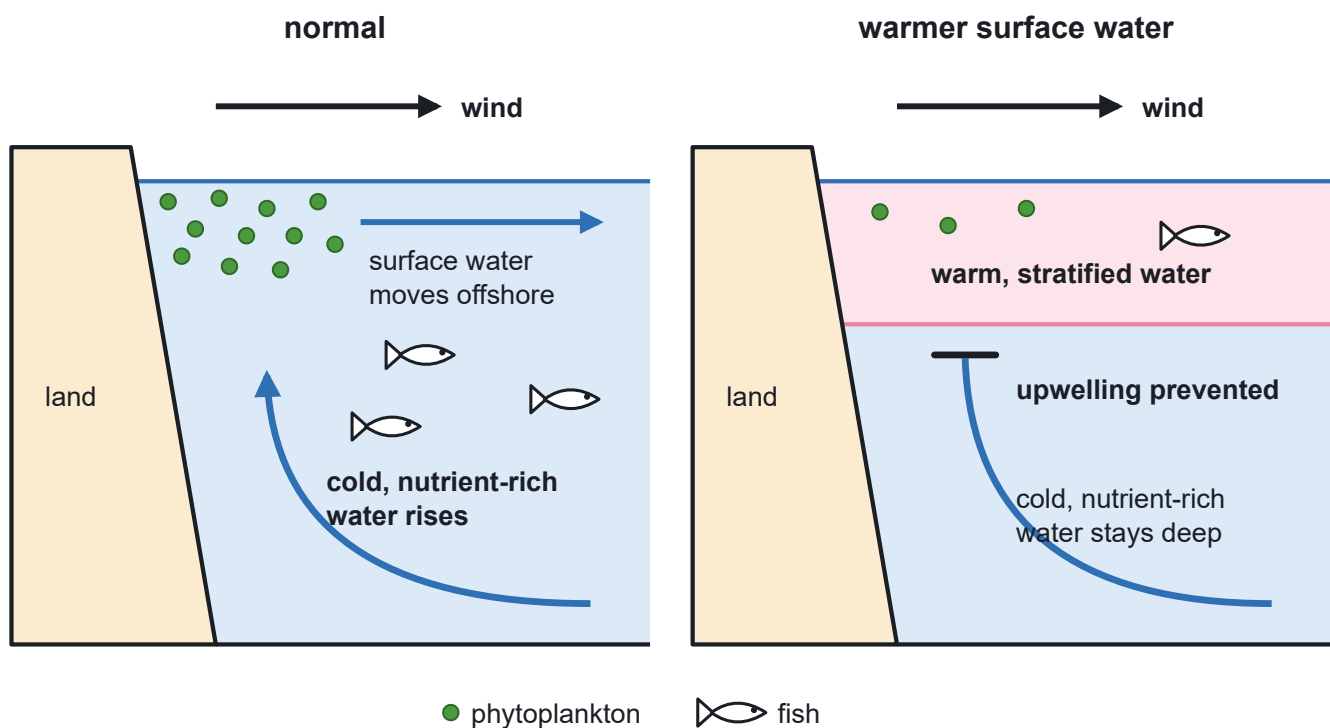
*Exam tip: In the exam you may use either the common name or the scientific name of an organism, for example emperor penguin or *Aptenodytes forsteri*.*

Nutrient upwelling and threats to coral reefs Spec D4.3.5, D4.3.7

Nutrient upwelling

In **upwelling** zones, currents bring cold, nutrient-rich water from the deep ocean to the sunlit surface, where phytoplankton use the nitrate and phosphate for growth. These zones support some of the most productive fisheries.

Warmer surface water is less dense and forms a stable layer that does not mix with the cold water below. This can **prevent nutrient upwelling** to the surface. Ocean primary production decreases, so less energy flows through marine food chains to fish, seabirds and marine mammals. Changes in currents also alter the timing of upwelling, so it may not match the breeding seasons of consumers.



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Warm, stratified surface water can **prevent nutrient upwelling**, lowering ocean primary production.

Threats to coral reefs

- **Ocean acidification:** increased CO₂ dissolves in seawater, forming carbonic acid. The pH falls and fewer carbonate ions are available, which suppresses **calcification**, so corals build calcium carbonate skeletons more slowly.
- **Coral bleaching:** increases in water temperature cause corals to expel their symbiotic algae (zooxanthellae). The corals turn white and lose their main source of food; if high temperatures last, they die.

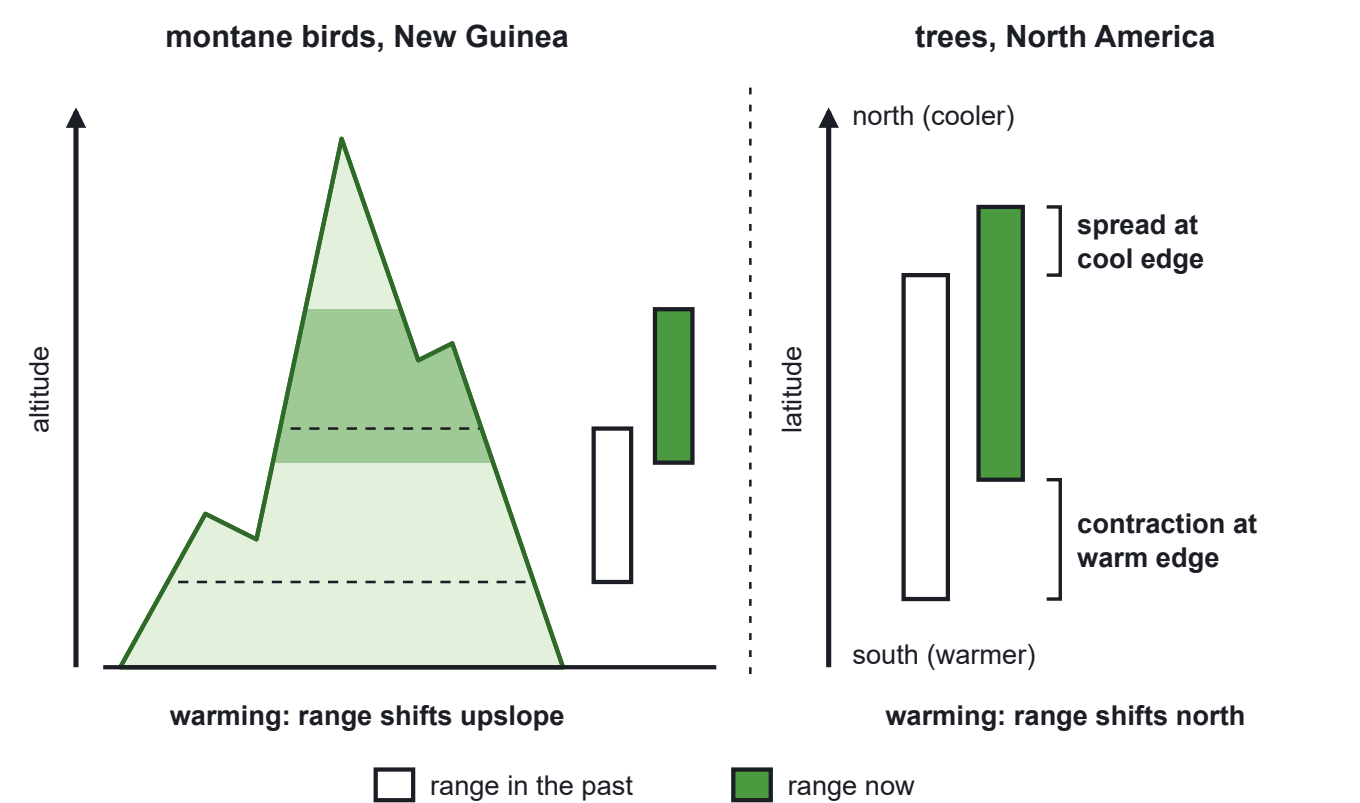
Corals build the reef structure that provides habitat and food for very many species. Loss of corals causes the **collapse of reef ecosystems**, so coral reefs are an example of potential ecosystem collapse.

Poleward and upslope range shifts Spec D4.3.6

Each species can only live within a range of temperatures. As the climate warms, the warm edge of a range becomes too hot and areas beyond the cool edge become suitable. So species ranges shift **towards the poles** and **upslope**, to higher altitudes.

Evidence-based examples	
Example	Evidence
Tropical-zone montane birds in New Guinea	Surveys repeated on the same mountain slopes decades apart found that many bird species now live higher up than before, with their upper and lower limits moved upslope .
North American tree species	Surveys of forest plots show some species with range contraction at their southern, warmer edge and northward spread at their cooler edge. Trees disperse slowly, so many ranges are shrinking faster than they spread.

Species on mountain tops and near the poles have nowhere further to move, so they are at particular risk of extinction.



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Warming shifts ranges **upslope** and **towards the poles** (schematic).

Afforestation, forest regeneration and peatland restoration Spec D4.3.8

Carbon sequestration is the capture of carbon dioxide from the atmosphere and its long-term storage, here as organic carbon in plants and soil.

Approach	What it involves
Afforestation	Planting trees on land that has not been forest for a long time
Forest regeneration	Allowing or helping forest to regrow on land where it has been cleared
Restoration of peat-forming wetlands	Blocking drains to rewet peatland, so waterlogged conditions return and peat forms again

Peat forms because waterlogged soil is anaerobic and acidic, so decomposers break down dead plant matter very slowly and carbon accumulates. Peat formation naturally occurs in waterlogged soils in temperate and boreal zones, and also very rapidly in some tropical ecosystems.

An active scientific debate		
Approach	For	Against
Plantations of non-native trees	Fast-growing species can absorb CO ₂ quickly	Often monocultures with low biodiversity; harvesting releases stored carbon
Rewilding with native species	Higher biodiversity; more resilient to pests and climate	May sequester carbon more slowly at first

Exam tip: When asked to evaluate, weigh both sides: speed of carbon uptake against biodiversity and long-term storage.

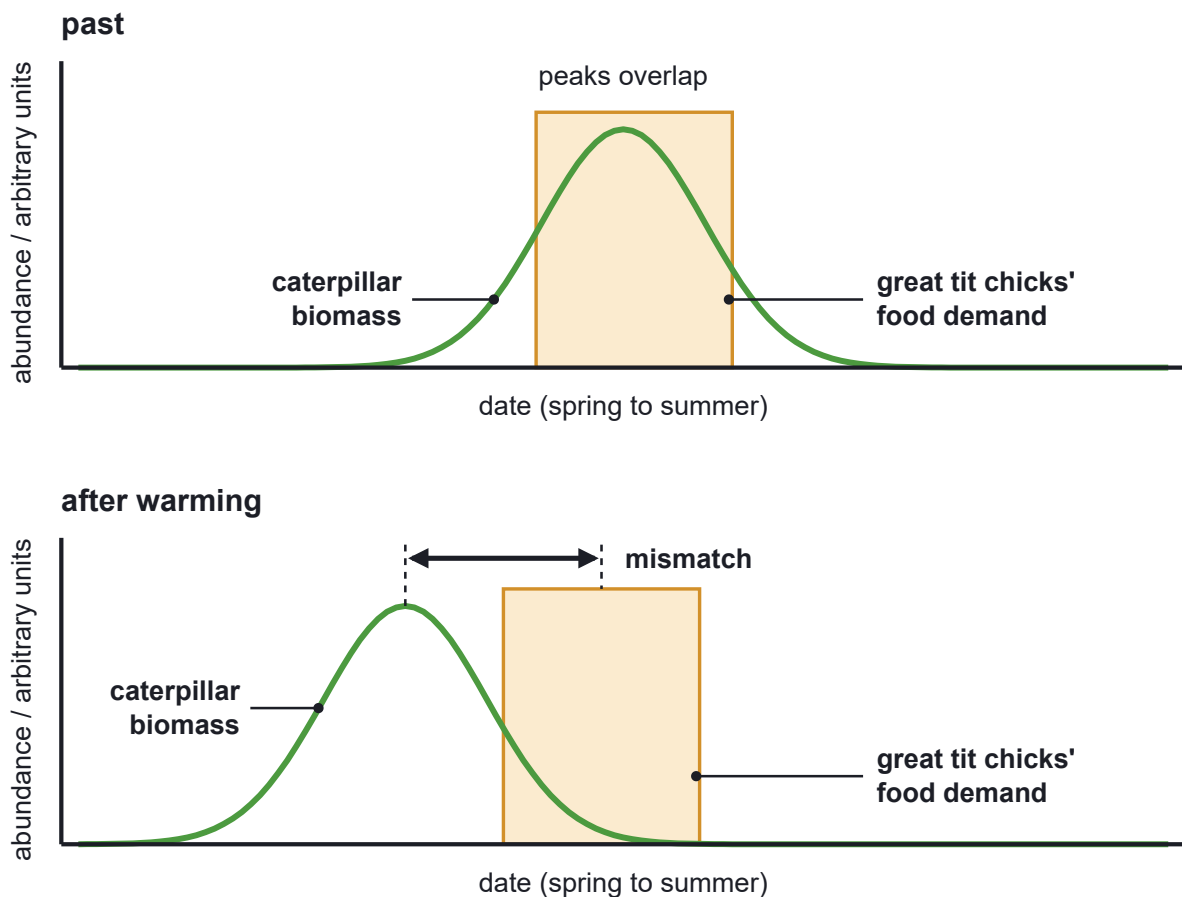
Phenology and disrupted synchrony Spec D4.3.9, D4.3.10 HL only

Phenology is research into the timing of biological events. Examples include flowering, budburst and bud set in deciduous trees, bird migration and nesting.

Two variables commonly act as cues: **photoperiod** (day length), which is not affected by climate change, and **temperature patterns**, which are. Within an ecosystem, temperature may act as the cue in one population and photoperiod in another.

Disruption to synchrony

Example	Cues	Effect of warming
Arctic mouse-ear chickweed (<i>Cerastium arcticum</i>) and migrating reindeer (<i>Rangifer tarandus</i>) in Greenland	Plant growth is cued by temperature; reindeer migration to calving grounds is cued by photoperiod	Plants grow earlier in warm springs, so peak food has passed when reindeer arrive and calve. Fewer calves survive.
Great tit (<i>Parus major</i>) and caterpillars in north European forests	Caterpillar emergence follows temperature and leaf budburst; great tit laying date changes less	Peak caterpillar biomass comes earlier, so chicks hatch after the peak and fewer survive.



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After warming, the caterpillar peak comes earlier but great tit chicks do not: a **mismatch** (illustrative).

Exam tip: Name the cue for each species. The mismatch only arises because the two populations respond to different cues.

Insect life cycles and evolution due to climate change Spec D4.3.11, D4.3.12 HL only

More insect life cycles per year

Insect development speeds up at higher temperatures, and warmer springs and autumns lengthen the breeding season. The **spruce bark beetle** (*Ips typographus*) used to complete one generation a year in much of northern Europe. In warmer years it can now complete two, or even three.

- Populations grow much faster, leading to outbreaks.
- Beetles bore into spruce bark and lay eggs; larvae feed beneath the bark, killing trees.
- Drought-stressed trees produce less resin to defend themselves, so damage increases further.

Evolution as a consequence of climate change

The **tawny owl** (*Strix aluco*) has two heritable colour variants, grey and brown. In cold, snowy winters, grey owls survive better than brown ones, probably because they are better camouflaged against snow and cope better with cold. As winters in Finland have had less snow cover, the survival disadvantage of brown owls has weakened, so their **fitness** has increased. The proportion of brown owls in the population has risen, a change in allele frequency.

Exam tip: Link back to natural selection: the colour is heritable, the selection pressure (snow cover) has changed, so the fitter variant leaves more offspring and allele frequencies change.

Quick check

1. Which two greenhouse gases does the guide limit anthropogenic causes to?
2. What is legacy carbon?
3. What causes coral bleaching?
4. **HL only** What is phenology?
5. **HL only** Why are spruce bark beetle outbreaks increasing?

Quick check answers

Climate change

1. Carbon dioxide and methane.
2. Old organic carbon in deep soil layers of boreal forest that survived earlier fires.
3. Increases in water temperature cause corals to expel their symbiotic algae.
4. Research into the timing of biological events.
5. Warming lets them complete more life cycles each year.