

Unit 9: Global Change

Unit 9 covers global change. It starts with stratospheric ozone depletion and the treaty that slowed it, then moves through the greenhouse effect, the evidence for climate change, the feedback loops that amplify warming, ocean warming and acidification, invasive species, endangered species, and the human impacts on biodiversity.

AP Environmental Science

Global Change

About 14 minutes to read

How to use this guide

Read it in order the first time. The unit builds from causes to consequences. Ozone-depleting chemicals and greenhouse gases come first, then the mechanisms that spread their effects, like feedback loops and ocean chemistry, and finally the living-world impacts, like invasive species, endangerment, and biodiversity loss. Exam questions often connect two topics, so notice where the sections link to each other.

After the first read, use the trap boxes and the table to review the distinctions that exam questions test most often. Finish with the practice questions, then complete the recall check on the last page out loud and note any items you cannot explain yet.

What this unit is worth. Global Change is about 15 to 20 percent of the AP Environmental Science exam. It is one of the heaviest units because it pulls together the atmosphere, the oceans, and the living world from earlier units. It rewards students who can trace a cause through a mechanism to an effect, like CO₂ to acidification to slower reef growth.

9.1 Stratospheric Ozone Depletion

The **ozone layer** sits in the stratosphere and absorbs most incoming UV radiation. That absorption is what shields life on Earth from DNA damage, skin cancer, and ecosystem harm. Without it, far more damaging ultraviolet light would reach the surface.

Ozone depletion is caused by human-made chemicals, mainly **chlorofluorocarbons (CFCs)**. When CFCs reach the stratosphere, ultraviolet light breaks them apart and releases chlorine, and the chlorine destroys ozone molecules. The worst losses happen over Antarctica each spring. This is where **polar stratospheric clouds** come in. The clouds provide ice surfaces that convert inactive chlorine into reactive forms, which intensifies the destruction. The clouds do not destroy ozone on their own. They make the CFC-driven destruction worse.

Trap. Polar stratospheric clouds are not a natural cause of ozone depletion. They only matter because they activate chlorine that came from human-made CFCs. If a question asks what causes ozone depletion, the answer is CFCs, not the clouds.

When stratospheric ozone decreases, more UV reaches the surface. In humans, **UV exposure** leads to skin cancer and cataracts.

9.2 Reducing Ozone Depletion

The **Montreal Protocol** is the international treaty that phases out the production and use of ozone-depleting substances such as CFCs. It worked because the chemicals were replaced with substitutes rather than eliminated outright.

One substitute is **hydrofluorocarbons (HFCs)**. HFCs do not deplete the ozone layer, so they solved the ozone problem, but some are strong greenhouse gases, which means the replacement traded an ozone problem for a climate problem. Reducing ozone depletion was a matter of swapping chemicals, not of cutting emissions overall.

Trap. The Montreal Protocol targets ozone-depleting substances. It is not a climate treaty. The **Kyoto Protocol**, which commits industrialized countries to reduce greenhouse gas emissions, is a different agreement for a different problem. Keep the two treaties and their targets straight.

9.3 The Greenhouse Effect

The **greenhouse effect** is the warming of Earth's surface by gases that trap outgoing infrared radiation. Sunlight warms the surface, the surface radiates heat as infrared, and gases like CO₂ and methane absorb some of that outgoing radiation and send it back down, keeping the surface warmer than it would otherwise be. The effect is natural. It is what makes Earth warm enough for life.

The **principal greenhouse gases** are carbon dioxide, methane, water vapor, nitrous oxide, and CFCs. **Water vapor** is a major one, but it behaves differently from the rest. It has a short atmospheric residence time, so it acts as a feedback rather than a forcing. Its concentration responds to temperature. When CO₂ warms the atmosphere, more water evaporates, and the extra water vapor amplifies the warming that the longer-lived gases started.

Global warming potential (GWP) compares gases by how much warming one unit of each causes, relative to CO₂, which is assigned a value of 1. The ranking matters for exam questions. CFCs rank highest, followed by nitrous oxide, then methane, with CO₂ as the reference at 1.

Trap. CO₂ drives most of the warming because there is so much of it, but its GWP is 1, the lowest on the scale. GWP measures potency per molecule, not total contribution. A question asking which gas has the highest GWP wants CFCs, not CO₂.

Trap. Water vapor is a feedback, not a forcing. Its short residence time means it cannot drive warming on its own. It amplifies warming that longer-lived gases start. If a question asks which gas initiates warming, water vapor is the wrong answer.

9.4 Increases in the Greenhouse Gases

When greenhouse gas concentrations rise beyond the natural baseline, the enhanced greenhouse effect drives global climate change. The effects include **rising sea levels** from melting ice sheets and the thermal expansion of ocean water, and **disease vectors** spreading from the tropics toward the poles as warmer zones shift. These changes alter population dynamics and push populations to move.

The **Kyoto Protocol** is the international agreement under which participating industrialized countries committed to reduce their greenhouse gas emissions. It is the climate counterpart to the Montreal Protocol, but it covers a different problem with different chemicals.

9.5 Global Climate Change

Climate change is not new in Earth's history. The planet has gone through major warming and cooling periods throughout geologic time, and the evidence is recorded in CO₂ data and **ice cores**. Ice cores trap ancient air bubbles, so they show how CO₂ and temperature moved together over hundreds of thousands of years. This record is what lets scientists say the current warming is different. The rate and the cause do not match the natural cycles.

The observed **effects of climate change** include rising temperatures, melting permafrost and sea ice, rising sea levels, and the displacement of coastal populations.

Atmospheric circulation moves heat around the planet, and climate change can alter the patterns. Winds generated by circulation transport heat, and temperature changes can shift **Hadley cells** and the jet stream, which changes weather patterns far from where the warming started.

Ocean currents do the same work in the oceans. The **ocean conveyor belt** carries heat throughout the world, and when these currents change, the effects on global climate are large, especially in coastal regions.

Sea-level change cuts both ways for marine ecosystems. Flooding continental shelves creates new shallow habitats, which helps some species. At the same time, deeper communities may fall below the photic zone, the sunlit layer where photosynthesis is possible, which harms them.

Soil is affected through temperature and rainfall changes, which reduce soil viability and increase erosion.

9.5 Global Climate Change, continued: feedback loops

Polar amplification is the observation that Earth's polar regions warm faster than the rest of the planet. Ice and snow at the poles reflect the most solar energy back to space, so when they melt, the surface gets darker and absorbs more heat, which warms it further. That is a positive feedback loop.

The **ice-albedo feedback** is the general version of the same mechanism. As Earth warms, ice and snow melt, so less solar energy is reflected back to space and more is absorbed, causing more warming. Albedo means reflectivity, so the name describes exactly what is being lost.

The Arctic adds another feedback. Melting sea ice and thawing tundra release greenhouse gases like **methane**, which was locked in the permafrost. More methane means more warming, which thaws more tundra.

Trap. In feedback loops, the names tell you the direction. Ice-albedo and Arctic methane are positive feedbacks, which means they amplify the original change. "Positive" here means reinforcing, not good. And in the ice-albedo feedback, the mechanism is reflection: melting ice means less solar energy is *reflected* back to space, not radiated.

Ice-dependent species are the living casualties of these feedbacks. Polar bears, seals, and other species that depend on ice for habitat and food lose ground as the ice retreats.

9.6 Ocean Warming

Ocean warming is caused by the increase in greenhouse gases in the atmosphere. The oceans absorb most of the extra heat trapped by the enhanced greenhouse effect, so they warm even though the gases are in the air.

Warming affects marine species through loss of habitat and through metabolic and reproductive changes. Many marine organisms are tuned to narrow temperature ranges, so even small shifts change when they breed and how fast they grow.

Coral bleaching is the most visible effect. When water gets too warm, corals expel the algae living inside their tissues. The algae give corals their color and much of their food, so without them the corals turn white. Some recover when temperatures drop. Some die.

Trap. Bleaching is caused by heat, not by acidification. Ocean warming drives bleaching. Ocean acidification damages coral skeletons. The two often appear in the same question because both harm reefs, but the mechanisms are different.

9.7 Ocean Acidification

Ocean acidification is the decrease in seawater pH caused primarily by increased atmospheric CO₂. The oceans absorb a large share of the CO₂ humans release, and dissolved CO₂ forms carbonic acid, which lowers pH. The process can be written as chemical equations, which the exam may ask you to follow.

The human contributors are the activities that raise atmospheric CO₂: burning fossil fuels, vehicle emissions, and deforestation. Anything that adds CO₂ to the air adds acidity to the ocean.

Acidification hits corals through their skeletons. Lower pH means fewer carbonate ions in the water, and corals need carbonate ions to build their calcium carbonate skeletons. With less available, reef growth slows.

Trap. Acidification and bleaching both harm corals, but through different chemistry. Bleaching is the loss of algae from heat. Acidification is the loss of carbonate ions from lower pH. If a question mentions skeletons or reef growth slowing, it is testing acidification.

9.8 Invasive Species

An **invasive species** is one that can live, and sometimes thrive, outside its normal habitat, and is considered invasive when it threatens native species. Not every introduced species is invasive. Some are harmless or even beneficial. The label applies when the species causes harm.

Invasive species tend to share traits. They are often **generalists** that can eat many foods and live in many conditions, and they are often **r-selected**, meaning they reproduce fast and in large numbers. Those traits let them outcompete native species for resources.

Control starts with prevention: ballast-water rules for ships, inspections at ports, and quarantines. Once a species is established, the options are mechanical removal, targeted biological controls such as introduced predators, and carefully applied chemical treatments. Prevention is far cheaper than removal.

9.9 Endangered Species

A variety of **factors can lead to endangerment**: extensive hunting, a limited diet, being outcompeted by invasive species, or having specific and limited habitat requirements. A species with a narrow niche has fewer options when conditions change.

Not every species faces the same risk from the same change. Species that can adapt to new conditions or move to a new environment are less likely to face **extinction**. Mobility and flexibility are the best defenses.

Selective pressures are any factors that change the behaviors and fitness of organisms within an environment. **Competition** is one of them. Species in an ecosystem compete for territory, food, mates, and habitat, and that competition can push a species toward endangerment or extinction.

Protection strategies include criminalizing poaching, protecting habitats, and passing legislation. The **Endangered Species Act** is the federal law that protects listed at-risk species and conserves the habitats they depend on.

9.10 Human Impacts on Biodiversity

HIPPCO is the acronym for the main factors decreasing biodiversity: habitat destruction, invasive species, population growth, pollution, climate change, and overexploitation. Habitat destruction is listed first because it is the largest driver.

Habitat fragmentation breaks large habitats into smaller, isolated areas. Roads and pipelines, clearing for agriculture or development, and logging all do it. Fragmentation matters differently for different species. **Wide-ranging species** suffer when fragments fall below their territory size. Small, sedentary species may persist in fragments that doom larger ones. Whether fragmentation harms a species depends on its needs.

Climate change causes **habitat loss** through changes in temperature, precipitation, and sea-level rise. A habitat does not need to be bulldozed to be lost. If the climate it depends on moves or disappears, the habitat is gone.

Domestication also reduces biodiversity. Honeybee colonies and domestic livestock are managed for economic returns, and breeding for a few traits narrows the genetic diversity of the organism.

Mitigation includes creating protected areas, building **habitat corridors** that connect fragments, promoting sustainable land use, and restoring lost habitats. **CITES**, the international agreement regulating trade in threatened and endangered species of wild fauna and flora, attacks the overexploitation side by controlling the market for rare species.

Confusions That Cost Points

PAIR	HOW TO KEEP THEM STRAIGHT
Montreal Protocol vs Kyoto Protocol	Montreal phases out ozone-depleting substances like CFCs. Kyoto commits industrialized countries to reduce greenhouse gas emissions. Ozone vs climate.
Greenhouse effect vs enhanced greenhouse effect	The greenhouse effect is natural and makes Earth habitable. The problem is the increase in greenhouse gases beyond the natural baseline.
GWP ranking	CFCs rank highest, then nitrous oxide, then methane, with CO ₂ as the reference at 1. CO ₂ contributes the most warming overall but has the lowest GWP per molecule.
Coral bleaching vs acidification damage	Bleaching comes from ocean warming expelling algae. Acidification damage comes from lower pH reducing the carbonate ions corals need for skeletons.
Positive vs negative feedback	Ice-albedo and Arctic methane are positive feedbacks, which means they amplify warming. "Positive" means reinforcing, not good.
Reflected vs radiated in ice-albedo	Melting ice means less solar energy is reflected back to space. Reflection is the mechanism. Radiated heat is a different part of the energy budget.
Polar stratospheric clouds vs CFCs	CFCs cause ozone depletion. The clouds only convert inactive chlorine into reactive forms, intensifying the loss. The clouds are not an independent natural cause.
Fragmentation effects by species	Wide-ranging species suffer when fragments fall below territory size. Small, sedentary species may persist in the same fragments. The effect depends on the species' needs.

Practice Questions

Original questions written for this guide in the style of the AP exam. Answers and explanations are on the next page, so complete the questions before checking them.

1. Which of the following gases has the highest global warming potential?

- A. Carbon dioxide
- B. Methane
- C. Nitrous oxide
- D. Chlorofluorocarbons

2. A student claims that polar stratospheric clouds are a natural cause of the Antarctic ozone hole. What is wrong with this claim?

- A. The clouds form over the Arctic, not over Antarctica.
- B. The clouds only intensify ozone loss by converting inactive chlorine from CFCs into reactive forms. They do not destroy ozone on their own.
- C. The clouds absorb UV radiation, which protects the ozone layer.
- D. Ozone depletion over Antarctica is caused by volcanic eruptions, not by clouds.

3. Which of the following best explains why ocean acidification slows coral reef growth?

- A. Warmer water causes corals to expel the algae living in their tissues.
- B. Lower pH reduces the carbonate ions that corals need to build their calcium carbonate skeletons.
- C. Increased CO₂ in the water blocks sunlight from reaching the reef.
- D. Acidic water dissolves the algae that give corals their color.

4. A highway is built through a forest, dividing it into isolated patches. A wide-ranging predator declines sharply, while a small sedentary rodent population remains stable. This best illustrates that

- A. habitat fragmentation affects all species equally.
- B. the effect of fragmentation depends on the species' needs, such as territory size.
- C. roads increase biodiversity by creating edge habitat.
- D. predators are always more vulnerable to extinction than prey.

Answer Key

- 1. D.** CFCs rank highest in global warming potential, followed by nitrous oxide, then methane, with CO₂ as the reference at 1. A is the trap of confusing total contribution with per-molecule potency; CO₂ drives most warming because there is so much of it, but its GWP is the lowest on the scale. B ranks below nitrous oxide. C ranks second, not first.
- 2. B.** Polar stratospheric clouds provide ice surfaces that convert inactive chlorine from CFCs into reactive forms, intensifying the loss. They do not destroy ozone on their own, so calling them a natural cause is wrong. A is factually wrong; the clouds do form over Antarctica. C invents a UV-absorbing role the clouds do not play. D substitutes a different false cause.
- 3. B.** Lower pH means fewer carbonate ions in the water, and corals need carbonate ions to build their calcium carbonate skeletons, so reef growth slows. A describes coral bleaching, which is caused by ocean warming, not acidification. C invents a light-blocking mechanism. D confuses the bleaching mechanism with the acidification mechanism.
- 4. B.** Wide-ranging species suffer when fragments fall below their territory size, while small, sedentary species may persist in fragments that doom larger ones. The outcome depends on the species' needs. A states the opposite of what the evidence shows. C is wrong because edge effects from fragmentation generally harm forest-interior species. D overgeneralizes from one example.

One-Page Recall Check

- Explain what the ozone layer does and what happens when it thins.
- State what causes ozone depletion and the role polar stratospheric clouds play.
- Name the treaty that phases out CFCs, and say what HFCs fixed and what they did not.
- Define the greenhouse effect and name the principal greenhouse gases.
- Explain why water vapor is a feedback rather than a forcing.
- Rank CO₂, methane, nitrous oxide, and CFCs by global warming potential.
- Describe two effects of increased greenhouse gases on sea level and disease.
- Explain how ice cores record past climate change.
- Describe the ice-albedo feedback and say whether it is positive or negative.
- Explain polar amplification.
- Describe the Arctic methane feedback.
- Explain how circulation changes and the ocean conveyor belt connect to climate.
- State the cause of ocean warming and two effects on marine species.
- Explain coral bleaching and name its cause.
- Explain ocean acidification and how it slows reef growth.
- List the traits that make a species likely to become invasive.
- Name three ways to control invasive species.
- List four factors that can lead to endangerment.
- Explain why some species are less vulnerable to extinction than others.
- State what the Endangered Species Act protects.
- Expand HIPPCO.
- Explain why fragmentation harms wide-ranging species more than small sedentary ones.
- Name three ways humans can mitigate biodiversity loss.

Where to go next. Turn every missed item above into flashcards and drill them spaced out over several days rather than in one sitting. In Rycal, open the AP Environmental Science deck. The deck covers the terms in this guide, and its practice questions target the same traps named here. If you have a test date, add it in the Test Planner. You can also start your next review with a Brain Dump, then check what you missed against this guide.

Key terms for this unit

Importance of stratospheric ozone, Causes of ozone depletion, UV exposure effects, CFC substitutes (HFCs), Montreal Protocol, Principal greenhouse gases, Water vapor residence time, Greenhouse effect, Global warming potential (GWP), Effects of increased greenhouse gases, Kyoto Protocol, Climate change through geologic time, Effects of climate change, Sea-level change and marine ecosystems, Circulation changes and heat transport, Ocean conveyor belt, Climate change and soil, Polar amplification, Ice-albedo feedback, Arctic methane feedback, Ice-dependent species, Cause of ocean warming, Ocean warming effects on marine species, Coral bleaching, Ocean acidification, Ocean CO₂ absorption, Human contributors to ocean acidification, Acidification and coral shells, Invasive species, Invasive species traits, Controlling invasive species, Factors leading to endangerment, Extinction vulnerability, Selective pressures, Competition and endangerment, Strategies to protect endangered species, Endangered Species Act, HIPPCO, Habitat fragmentation, Fragmentation scale varies by species, Climate change and habitat loss, Domestication and biodiversity, Mitigating