BIOZONE

ENVIRONMENTAL SCIENCE

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ENVIRONMENTAL SCIENCE

This fourth edition of **BIOZONE**'s Environmental Science combines the very best features of a light textbook with the utility of a workbook. This innovative hybrid, known as an interactive worktext, eliminates the need for a separate textbook, offering an all-in-one educational resource.

It's full color, highly visual content brings the subject to life in an engaging and thought-provoking manner. The four themes introduce students to our planet's physical and biological systems and the ways in which humans interact with them, **Earth's Systems**, **Living World**, **Global Resources** and **Global Change**.

This new edition includes engaging, real-world data on subjects relevant to students, such as fast fashion and mass travel.

ISBN: 978-1-99-101409-2
Edition: 4th (2025)
No. Pages: 382

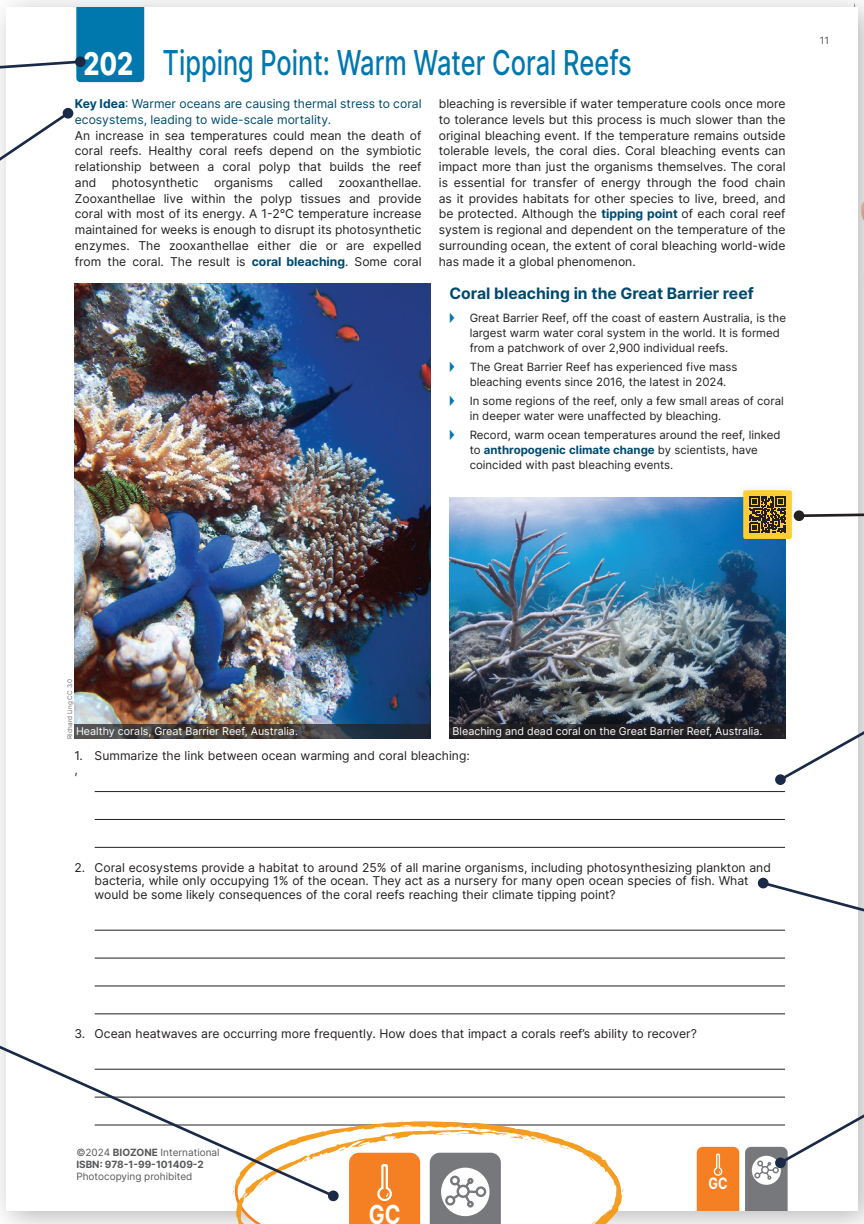
Activity number
Activities are numbered to make navigation through the book easier.

Key Idea
Each activity has a key idea. It helps you to understand where the activity's emphasis lies.

Content organization
Logically organized content makes it easier for you to access and engage with the information.

Comprehensive, engaging diagrams
Engaging, high quality diagrams provide a visual focus whilst delivering important information in an accessible format.

Tab system
Color coded tabs provided easy navigation through the four sections of the worktext. Identify the section of the worktext you The gray tab indicates there is support material on BIOZONE's Resource Hub.



11

202 Tipping Point: Warm Water Coral Reefs

Key Idea: Warmer oceans are causing thermal stress to coral ecosystems, leading to wide-scale mortality.

An increase in sea temperatures could mean the death of coral reefs. Healthy coral reefs depend on the symbiotic relationship between a coral polyp that builds the reef and photosynthetic organisms called zooxanthellae. Zooxanthellae live within the polyp tissues and provide coral with most of its energy. A 1-2°C temperature increase maintained for weeks is enough to disrupt its photosynthetic enzymes. The zooxanthellae either die or are expelled from the coral. The result is **coral bleaching**. Some coral bleaching is reversible if water temperature cools once more to tolerance levels but this process is much slower than the original bleaching event. If the temperature remains outside tolerable levels, the coral dies. Coral bleaching events can impact more than just the organisms themselves. The coral is essential for transfer of energy through the food chain as it provides habitats for other species to live, breed, and be protected. Although the **tipping point** of each coral reef system is regional and dependent on the temperature of the surrounding ocean, the extent of coral bleaching world-wide has made it a global phenomenon.

Coral bleaching in the Great Barrier reef

- Great Barrier Reef, off the coast of eastern Australia, is the largest warm water coral system in the world. It is formed from a patchwork of over 2,900 individual reefs.
- The Great Barrier Reef has experienced five mass bleaching events since 2016, the latest in 2024.
- In some regions of the reef, only a few small areas of coral in deeper water were unaffected by bleaching.
- Record, warm ocean temperatures around the reef, linked to **anthropogenic climate change** by scientists, have coincided with past bleaching events.

Healthy corals, Great Barrier Reef, Australia.

Bleaching and dead coral on the Great Barrier Reef, Australia.

1. Summarize the link between ocean warming and coral bleaching:

2. Coral ecosystems provide a habitat to around 25% of all marine organisms, including photosynthesizing plankton and bacteria, while only occupying 1% of the ocean. They act as a nursery for many open ocean species of fish. What would be some likely consequences of the coral reefs reaching their climate tipping point?

3. Ocean heatwaves are occurring more frequently. How does that impact a corals reef's ability to recover?

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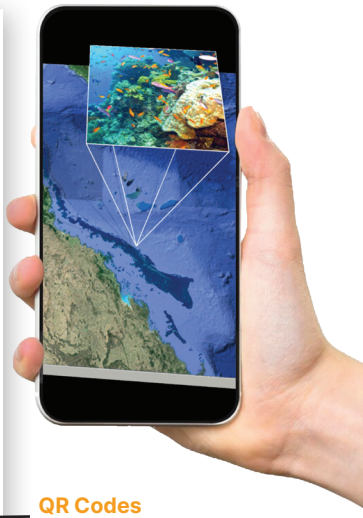


QR Codes
Scan the QR code to directly interact with 3D models (above).

Write-on answers
Input your answers directly onto the page. This becomes a record of work and helps you revise for tests and exams.

Direct questioning
A direct questioning style helps you to easily identify what is being asked.

See inside back cover for details about **Resource Hub**

See our website for more details and local pricing
www.BIOZONE.com

Environmental Science

All of the Earth's systems are connected. Changes in one system may cause changes in other systems.

Environmental science is an interdisciplinary field of study involving both natural and social sciences.

The Earth's Systems

Geological systems
- Age of the Earth
- The Earth's surface
- Plate tectonics

The atmosphere
- The atmosphere
- Atmospheric circulation
- Weather and climate

Global water resources
- Oceanic water
- Fresh water

Rocks and soil
- Rocks and minerals
- Soil dynamics

The resources used by humans are a result of constantly changing global systems.

The Living World

Ecosystems
- Biomes and ecosystems
- Energy flow
- Species interactions

Natural ecosystem change
- Biogeochemical cycles
- Ecosystem stability

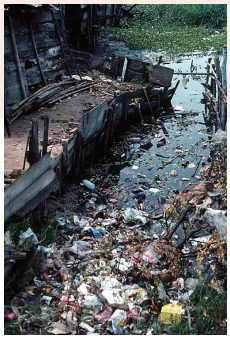
Populations
- Features of populations
- Population growth

Investigating ecosystems
- Sampling populations
- Abiotic factors
- Classification

Complex systems arise as a result of the interactions between organisms and their environment.

Resources must be carefully managed to ensure they are available to future generations.

Understanding environmental systems is critical to understanding the environmental effects of human activities.



Global Resources

Food production
- Agriculture
- Land management

Earth's Resources
- Fisheries
- Irrigation

Energy sources
- Energy
- Non-renewable energy
- Renewable energy

Energy security
- Energy conservation
- Energy threats
- Energy storage

Global Change

Types of pollution
- Air pollution
- Water pollution
- Ozone depletion

Impacts and treatments
- Treating pollution
- Impacts of pollution
- Disasters

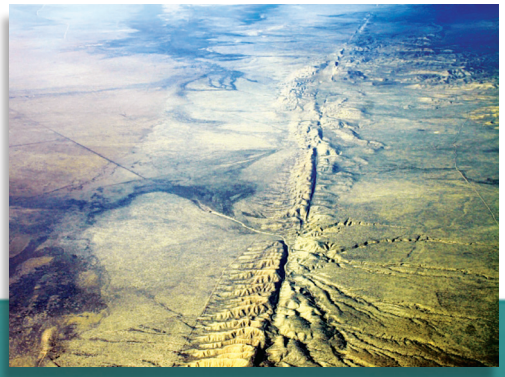
Conserving biodiversity
- Loss of biodiversity
- Maintaining biodiversity

Climate change
- Climate change science
- Tipping points

7 Plate Boundaries

Key Idea: When tectonic plates meet, they form either convergent, divergent, or transform boundaries.

The outer rock layer of the Earth, comprising the **crust** and upper **mantle**, is called the **lithosphere** and it is broken up into seven large, continent-sized tectonic plates and about a dozen smaller plates. Throughout geological time, these plates have moved about the Earth's surface, shuffling continents, opening and closing oceans, and building mountains. The size of the lithospheric plates is constantly changing, with some expanding and some getting smaller. These changes occur along plate boundaries which are marked by well-defined zones of seismic and volcanic activity. Plate growth occurs at **divergent boundaries** along sea floor spreading ridges, e.g. the Mid-Atlantic Ridge and the Red Sea, whereas plate attrition occurs at **convergent boundaries** marked by deep ocean trenches and subduction zones. Divergent and convergent zones make up approximately 80% of plate boundaries. The remaining 20% are transform boundaries, where two plates slide past one another with little change in the size of either plate.



The San Andreas **fault** is a transform boundary running for over 1000 km through California.

1. Describe what is happening at each of the following plate boundaries, and identify an example in each case:

   (a) Convergent plate boundary: _____

   _____

   _____

   (b) Divergent plate boundary: _____

   _____

   _____

   (c) Transform plate boundary: _____

   _____

   _____

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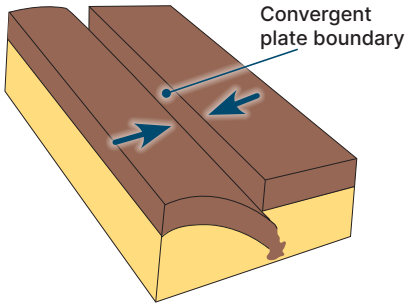
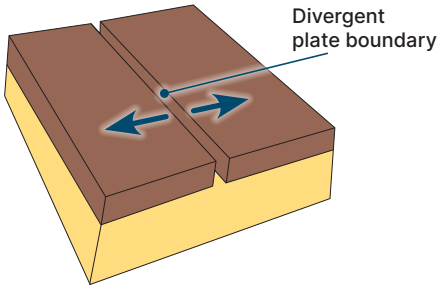
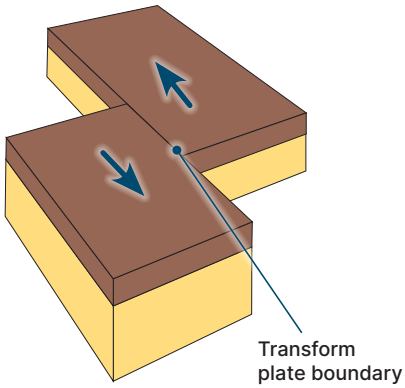


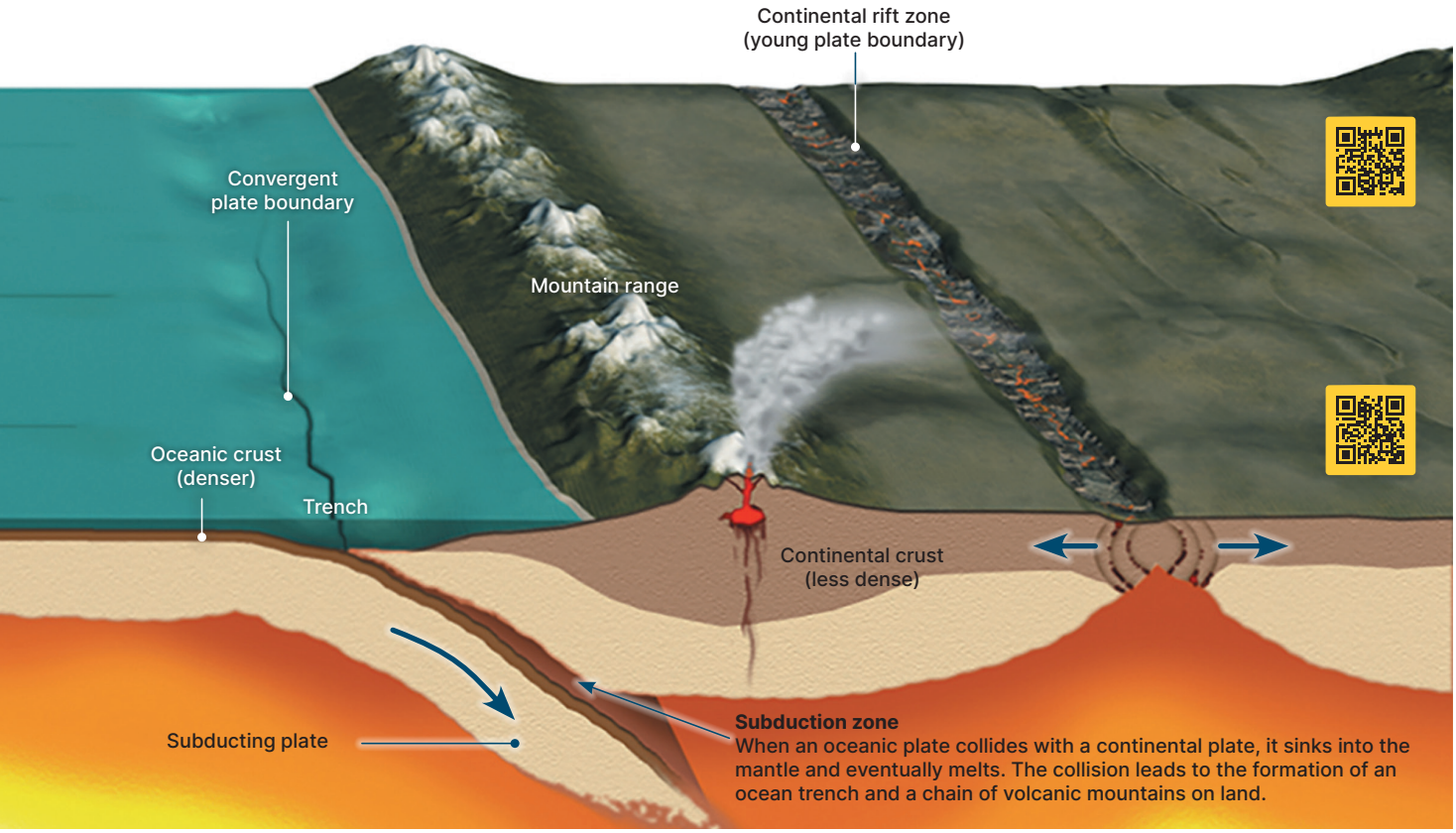
Plate boundaries moving towards each other are called convergent plate boundaries. Where oceanic **crust** and continental crust meet, the oceanic crust will subduct under the continental crust, creating a subduction zone. Volcanoes normally form along the continental border of a subduction zone. When continental crusts collide, huge mountain ranges such as the Himalayas can form.



Divergent plate boundaries form where the tectonic plates are moving away from each other. These are commonly found along the mid ocean ridges, but occasionally are seen on land, as in the Great Rift Valley and Iceland. Divergent boundaries are also known as constructive boundaries as they produce new crust from the upwelling of magma.



Transform boundaries are formed when the tectonic plates are moving past each other. They are, therefore, neither constructive nor destructive. Examples include the San Andreas fault in California and the Alpine Fault in New Zealand.



2. Identify the type of plate boundary at which each of the following occurs:

   (a) Mountain building: _____ (c) Creation of new ocean floor: _____

   (b) Subduction: _____ (d) Island arc: _____

3. (a) Explain why the oceanic crust subducts under the continental crust in a subduction zone:

   _____

   _____

   (b) What causes volcanoes to form along the continental plate boundary of a subduction zone?

   _____

   _____

   _____

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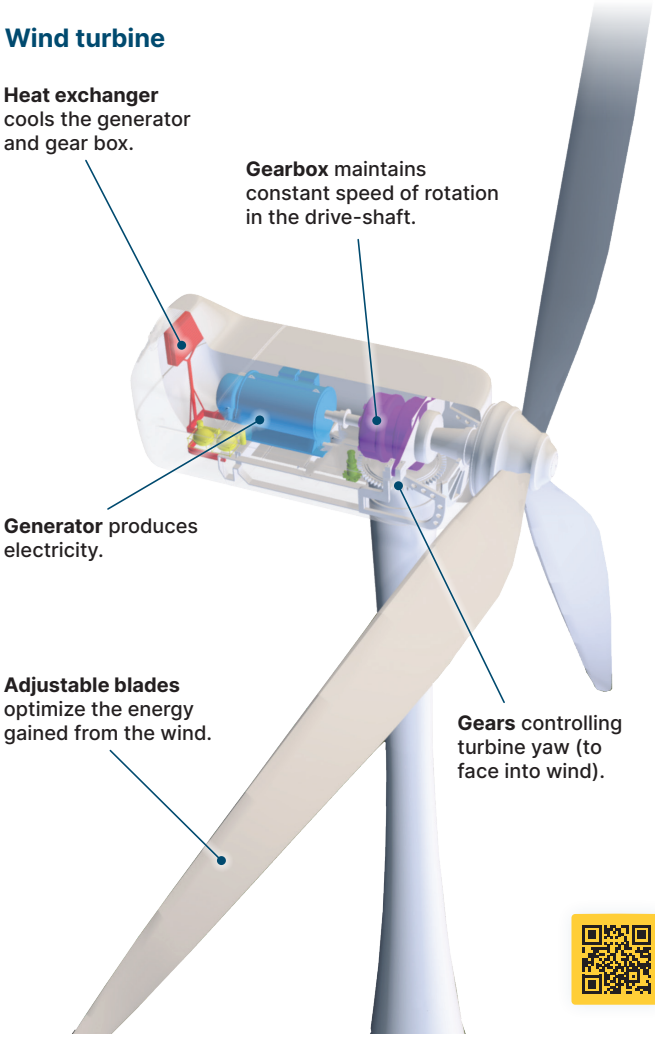
126 Wind Power

Key Idea: Wind power provides a relatively simple and scalable way to produce electricity.

Wind power has been used for centuries to provide the mechanical energy to pump water or run milling machinery. Today, it is mainly used to produce electricity. Wind power is becoming increasingly reliable and cost effective as the technology develops and turbines are able to operate in a range of conditions and wind speeds. In fact **wind energy** is one of the cheapest types of energy to build, maintain, and use. Globally, wind power is steadily increasing in generation capacity, but wind is a variable energy provider. There can be problems matching output to demand, such as during seasonal demands and low (or extremely high) winds. This means systems for managing and distributing electricity will be required as well as backup or base load electricity supplies, e.g. hydro or geothermal power.

Wind turbine



Wind farms often cover large areas of land but turbines can be designed to operate at sea and, on a smaller scale, along highway edges. The scalability of **wind turbines** makes them simple to install in many locations, with turbine sizes ranging from a few metres to over 200 metres in diameter.

At the end of 2022, the power output from wind turbines was around 7% of global electricity production. Global installed capacity was more than 800 GW. Electricity generation from wind is rising every year.

1. A typical wind turbine produces around 2.3 MW. The average house uses 30 kWh of energy per day (a kilowatt hour is the equivalent of 1000 joules of energy per second (1kW) running for 1 hour). Calculate the following:

   (a) The minimum number of wind turbines required to power a town of 20,000 households:

   _____

   _____

   (b) Wind turbines cost around $1.3 million per MW of energy production to build. What will the be the cost of (a) above?

   _____

   (c) The cost of building, running, and maintaining wind turbines over their 20 year lifetimes is about $50 per MWh. What could the 20,000 households using the wind turbines above expect to pay in dollars per year for the use of electricity provided by the wind turbines?

   _____

   _____

   (d) Why can households actually expect to have to pay a lot more than this? _____

   _____

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Environmental effect of wind turbines

- Over their entire life cycle, wind turbines produce some of the lowest greenhouse gas emissions of any electricity production facility. This includes mining of minerals, manufacture and installation, and lifetime use.
- Similar to solar power plants, wind farms require large, open spaces and therefore tend to be in rural areas. This has led to what is often called 'industrialization of the country' and 'energy sprawl'. This includes the spreading of access roads and transmission networks, all of which affect the visual appeal of the areas around wind farms.
- There is documented evidence of wind farms affecting flying animals, especially where they are placed at the top of hills. Birds and bats following the contours of these hills are struck by turbine blades and killed.
- The blades have a service life of between 10 and 20 years and are generally made of fiberglass or (increasingly) carbon fiber, and there is no easy way of recycling these. When their lifespan ends, the blades must be disposed of in landfills.
- Because wind turbines sit on single, tall towers well above the ground, the area underneath them is minimally affected. Therefore, if they are sited on agricultural ground, the land can continue to be used for agriculture (right).

Wind power	
Advantages	**Disadvantages**
• No emissions	• Production of visual and noise pollution
• Little ground disturbance during or after construction	• Requires steady winds
• Compact and transportable to most locations	• Can interfere with the flight paths of flying animals
• Can be located in many areas (even at sea)	• Much of actual cost to user is repaying start-up costs.
• Cost certainty. Operating cost is not affected by fuel prices	• Back up systems are required in low winds

2. A major problem with generating electricity is the effect of the facility on the environment. Describe how wind power solves some of these problems. What problems does it create?

3. Explain why increasing uptake of wind power will require better management of the electrical grid: _____

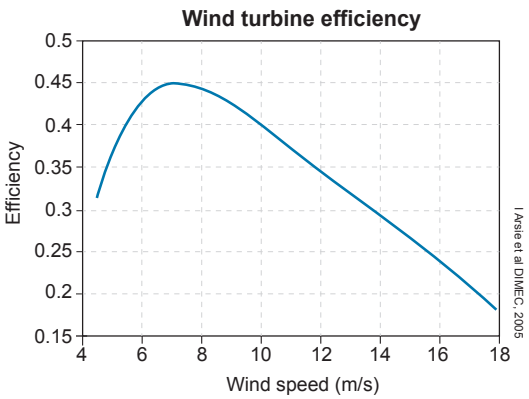
4. (a) From the graph on the right, what is the optimum wind speed for wind turbine use?

   _____

   (b) What happens to efficiency as wind speed increases?

   _____

5. Wind turbine towers have become progressively taller. Why might this help increase reliability of output?



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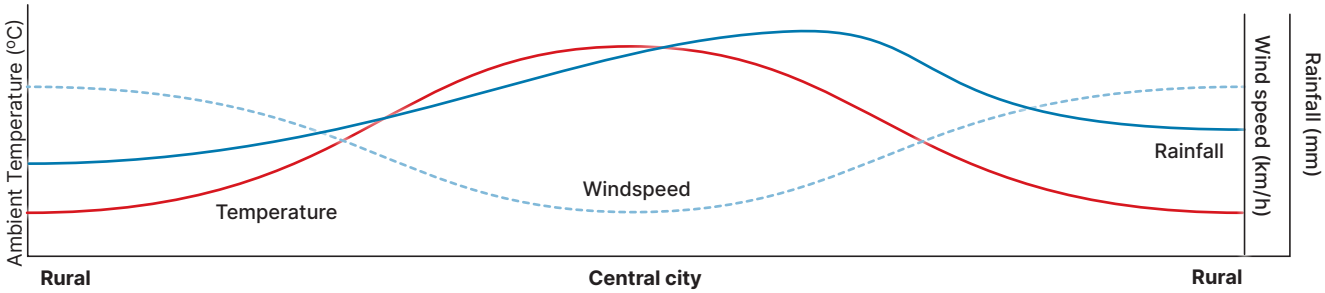
150 Cities and Air Pollution

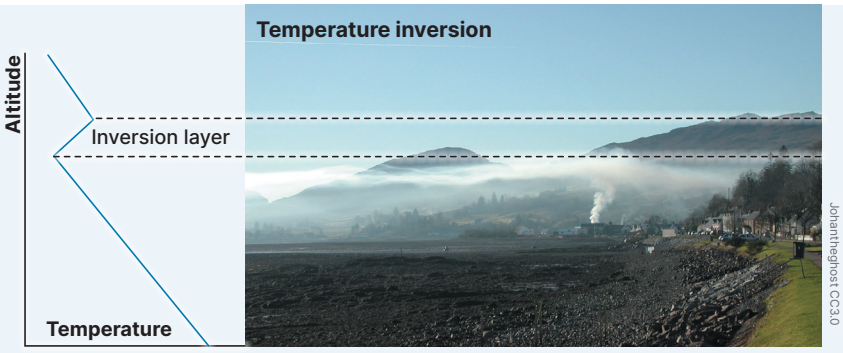
Key Idea: The heat generated from cities can affect the microclimate and trap air pollution in the form of smog.

Cities contain vast amounts of radiative surfaces, and so tend to heat up very quickly during the day. This region of hot air modifies the local climate, resulting in quite different weather in and near the city than in the surrounding rural areas, especially in large inland cities. The heat island effect of cities produces a rising current of air above the city which results in heavier rainfall and higher air temperatures, while trapping **photochemical smog**.



- The majority of urban areas are covered with concrete, asphalt, and iron so they tend to absorb energy and then heat up faster than surrounding rural areas and retain the heat longer. Average temperatures in a city can often be between 5-10° C higher than surrounding rural land.
- City environments also affect rainfall. Hot air rising above a city carries more moisture with it than cool air. Wind moves this air away from the city and, as it cools, the moisture is lost as rain.
- Runoff of water after rain is higher in the urban environment due to the large paved surface area. Stormwater systems catch much of this runoff (up to 70% of the rain that falls) and funnel it into rivers, which can cause them to rise and fall rapidly.
- Wind within a city is often hampered or channeled by buildings with some parts of a city acting like wind tunnels. However, overall wind speed may be 20-30% lower in the city than in rural areas.

Many areas around the world experience the weather phenomenon of temperature inversion. This occurs when a layer of warm air sits on top of a layer of cool air. The cool, dense air remains close to the ground. In urban areas, smoke and other air pollutants can become trapped and concentrated due to a phenomenon called temperature inversion. This prevents them from rising to higher altitudes. As a result, **pollutants** like photochemical smog can accumulate and linger in the city. This may create serious health issues.



1. (a) Explain why the ambient temperature in a city is often higher than that of the surrounding rural land:

_____

_____

(b) What is the effect of cities on rainfall? _____

_____

2. Explain why an inversion layer above a city can have serious health effects: _____

_____

_____

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Photochemical smog

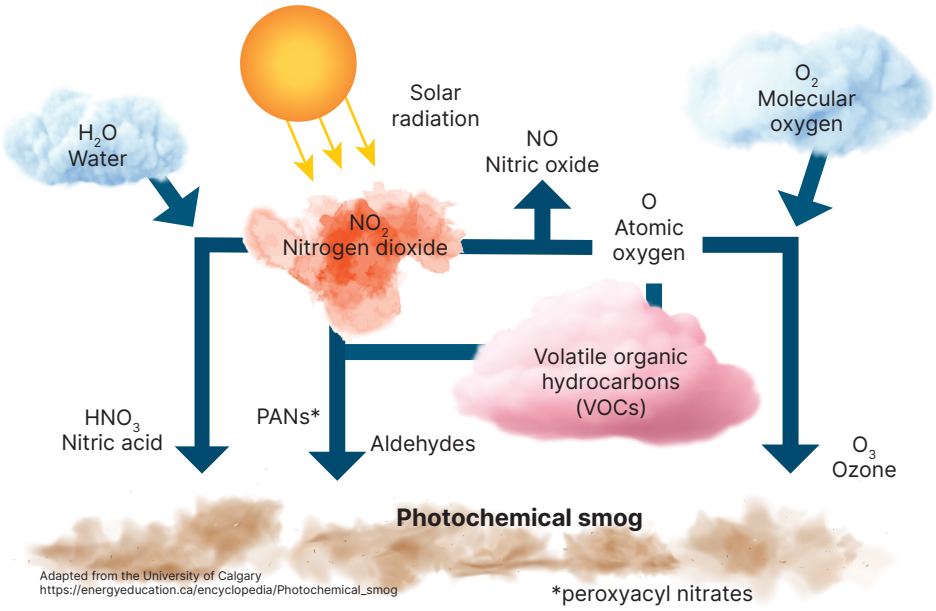
- Smog (a joining of the words smoke and fog) is a type of **air pollution**.
- Summer smog is also called photochemical smog and forms mainly in the warmer months. It is characterized by high levels of ground level ozone.
- Nitrogen oxides (NOx) from vehicle emissions or **pollutants** from coal fired industrial processes react in the atmosphere in the presence of sunlight to form the secondary pollutants that make up photochemical smog.
- This is a serious problem in many large cities around the world and it can cause many health problems. It mainly affects the respiratory (breathing) system. Emphysema, asthma, chronic bronchitis, lung infections, and cancers are caused by, or made worse from, exposure to photochemical smog. Eye and nose irritation, birth defects and low birth weights are also linked to prolonged exposure to photochemical smog.


Smog day and sunny day (Fanhe, China)

Tomskyhaha CC 4.0

How does photochemical smog form?

- The largest contributor to photochemical smog is vehicle emissions (exhaust fumes). Photochemical smog tends to form in the morning in large cities because vehicle emissions are high as a result of large numbers of people traveling to work.
- The nitrogen oxides produced by the car engines enter the atmosphere where, in the presence of sunlight, they react with volatile organic compounds (VOCs), specifically hydrocarbons, to form photochemical smog (diagram below). VOCs are found in the atmosphere as a result of **human activity** such as burning fossil fuels and also from naturally occurring processes.
- A feature of VOCs is that they have a high vapor pressure resulting from a low boiling point. This feature causes VOCs to evaporate (liquid → vapor) or sublimate (solid → vapor) at room temperature, i.e. they easily vaporize.
- Nitrogen oxides may also react with sunlight and then combine with molecular oxygen (O_2) to produce ozone (O_3). Whereas NO_2 levels peak in the morning, ozone production peaks in mid-late afternoon after the morning exhaust fumes have had time to react in the sunlight. The ozone in photochemical smog is called ground level ozone because it is located relatively close to the ground. This distinguishes it from **stratospheric ozone** which is formed naturally when sunlight energy splits molecular oxygen. Ground level ozone is regarded as a pollutant.



Adapted from the University of Calgary
https://energyeducation.ca/encyclopedia/Photochemical_smog


Photochemical smog over Mexico City, 2010

Fidel Gonzalez cc 3.0

3. Suggest why most cities experience lower levels of smog at the weekend compared to weekdays:

4. Use the diagram above to outline how nitrogen oxides form the air pollutants in photochemical smog:

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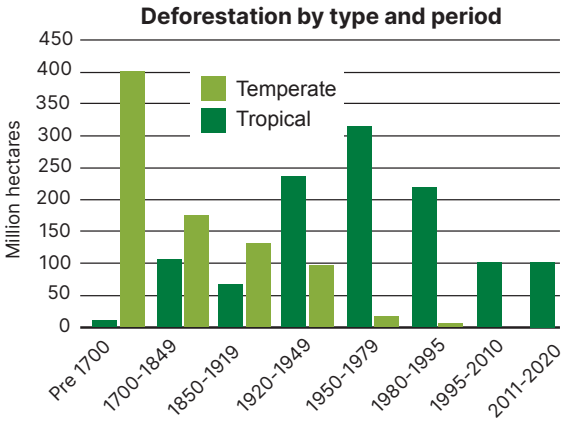
171 Tropical Deforestation

Key Idea: Deforestation continues to reduce the world's tropical rainforests, with large areas still at significant risk.

Tropical rainforests prevail in places where the climate is very moist and warm throughout the year. They account for 45% of the world's forest type. Almost half of the world's rainforests are in just three countries: Indonesia in Southeast Asia, Brazil in South America, and Zaire in Africa. Much of the world's **biodiversity** resides in rainforests, particularly in **biodiversity hotspots**. **Deforestation** will contribute to climate change by significantly reducing the amount of carbon capture and storage through photosynthesis. In the Amazon, 75% of deforestation has occurred within 50 km of Brazil's roads. Many potential drugs could still be discovered in rainforest plants, and loss of **species** through deforestation may mean they will never be found. Rainforests can provide economically sustainable crops for local people.

Deforestation

- At the end of the last glacial period, about 10,000 years ago, forests covered around 45% of the Earth's land surface. Forests now cover about 31% of Earth's surface. These include the cooler temperate forests of North and South America, Europe, China, and Australasia, and the tropical forests of equatorial regions.
- Over the past 5000 years, approximately 1.8 billion hectares of forest cover have been lost. In the past decade alone, there has been a net loss of around 4.7 million hectares of forest each year.
- The temperate regions, such as Europe, where human civilizations have existed for a long time, have experienced significant damage due to deforestation. However, currently, the majority of deforestation is happening in tropical regions.
- The intensive clearing of forests during the settlement of newly discovered lands has resulted in significant landscape alterations and permanent changes, leading to a decrease in biodiversity.

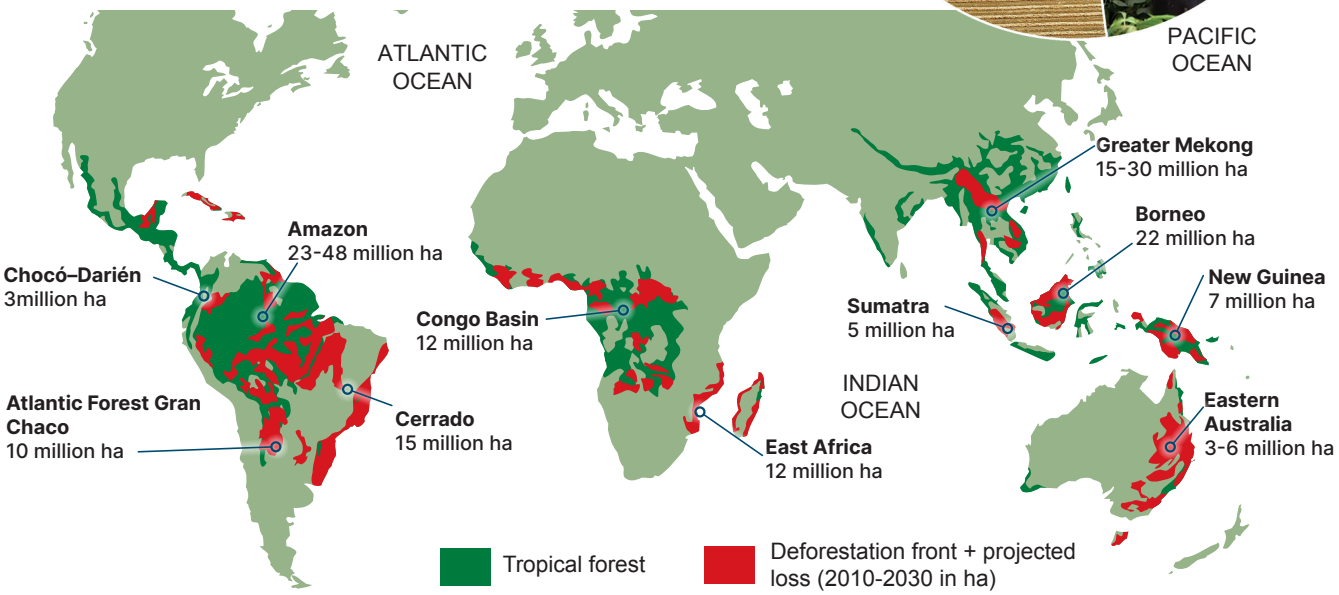


Data Source: Vlados et al. (2019) New globalization dynamics

Causes of deforestation

- Deforestation is the end result of many interrelated factors which often center around socioeconomic drivers. In many tropical regions, most deforestation is the result of small-scale family farming: poverty can be partially solved by clearing small areas of forest and making family plots (subsistence farming).
- However, huge areas of forests have been cleared for agriculture, including ranching and palm oil plantations. These produce revenue for governments through taxes and permits, creating an incentive to clear more forest.
- Just 14% of deforestation is attributable to commercial logging although, combined with illegal logging, it may be much higher.

Tropical forest deforestation risk areas - projected 2010-2030



Data Source: Olsen, D (2020) Conservation Earth

It is important to distinguish between deforestation involving primary (old growth) forest and deforestation in plantation forests. Plantations are regularly cut down and replaced, which can artificially inflate a country's apparent forest cover or rate of deforestation. The loss of primary forests is far more important as these are refuges of high biodiversity, including rare species, many of which are not found anywhere else in the world.

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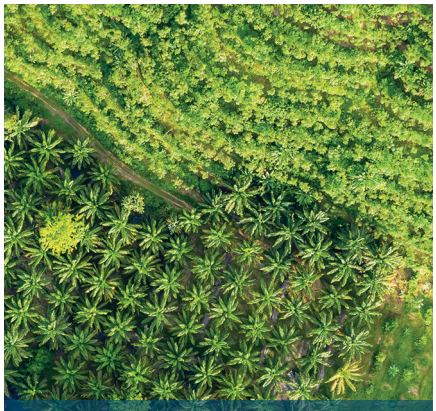
New road to Ilheus, Bahia, Amazon

The building of new road networks into regions with tropical rainforests causes considerable environmental damage. In areas with very high rainfall there is an increased risk of erosion and loss of topsoil.

Amazon leaf mantis

Up to 80% of Earth's terrestrial species are found in tropical rainforests. Many tropical species are endemic to specific parts of the forest or tree species. Loss of these areas could exterminate hundreds of species.



Palm oil plantations in rainforest

The soil in tropical rainforests in typically poor and the layer thin. Once the trees are removed and crops planted the soil quickly loses its nutrients and productivity decreases within a few seasons.

1. Identify the three main human activities that cause tropical deforestation and briefly describe their detrimental effects:

   (i) : _____

   (ii) : _____

   (iii) : _____

2. Describe the trend in tropical deforestation compared to temperate deforestation over the last 300 years:

   _____

   _____

3. Deforestation in tropical regions can be hard to reverse, even after plantations and crops have been removed and new trees are planted. Suggest why this might be so:

   _____

   _____

   _____

4. Why might building roads through primary forests have long-term negative effects on the ecosystem beyond the immediate damage caused by road construction?

   _____

   _____

   _____

5. Suggest some advantages of stopping deforestation in Borneo for both animals and humans:

   _____

   _____

   _____

   _____

   _____

   _____

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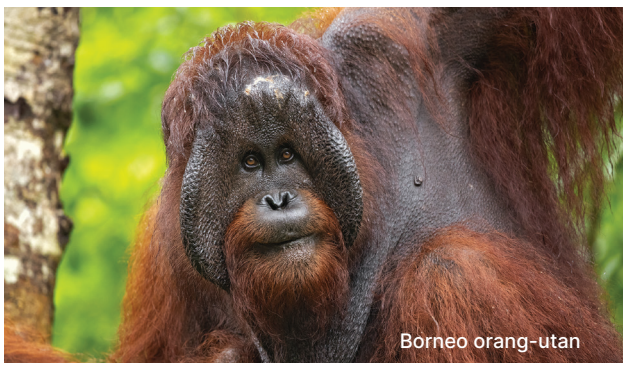
   _____



Borneo orang-utan

Deforestation is causing habitat loss for Borneo orang-utan (*Pongo pygmaeus*) which is projected to affect 26,000 apes by 2032: nearly one quarter of the total population. The orang-utan is called an 'umbrella species'. It needs large tracts of habitat to survive and its **conservation** will also indirectly protect many co-habiting species.

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207 Tipping Point: Warm Water Coral Reefs

Key Idea: Warmer oceans are causing thermal stress to coral ecosystems, leading to wide-scale mortality.

An increase in sea temperatures could mean the death of coral reefs. Healthy coral reefs depend on the symbiotic relationship between a coral polyp that builds the reef and photosynthetic organisms called zooxanthellae. Zooxanthellae live within the polyp tissues and provide coral with most of its energy. A 1-2°C temperature increase maintained for weeks is enough to disrupt its photosynthetic enzymes. The zooxanthellae either die or are expelled from the coral. The result is **coral bleaching**. Some coral bleaching is reversible if water temperature cools once more to tolerance levels but this process is much slower than the original bleaching event. If the temperature remains outside tolerable levels, the coral dies. Coral bleaching events can affect more than just the organisms themselves. The coral is essential for transfer of energy through the food chain as it provides habitats for other species to live, breed, and be protected. Although the **tipping point** of each coral reef system is regional and dependent on the temperature of the surrounding ocean, the extent of coral bleaching world-wide has made it a global phenomenon.

Richard Ling CC 3.0

Healthy corals, Great Barrier Reef, Australia.

Coral bleaching in the Great Barrier Reef

- Great Barrier Reef, off the coast of Eastern Australia, is the largest warm water coral system in the world. It is formed from a patchwork of over 2,900 individual reefs.
- The Great Barrier Reef has experienced five mass bleaching events since 2016, the latest in 2024.
- In some regions of the reef, only a few small areas of coral in deeper water were unaffected by bleaching.
- Record, warm ocean temperatures around the reef, linked to **anthropogenic climate change** by scientists, have coincided with past bleaching events.

Bleaching and dead coral on the Great Barrier Reef, Australia.

1. Summarize the link between ocean warming, and coral bleaching:

2. Coral ecosystems provide a habitat for around 25% of all marine organisms, including photosynthesizing plankton and bacteria, while only occupying 1% of the ocean. They act as a nursery for many open ocean species of fish. What would be some likely consequences of the coral reefs reaching their climate tipping point?

3. Ocean heatwaves are occurring more frequently. How does this affect a coral reef's ability to recover?

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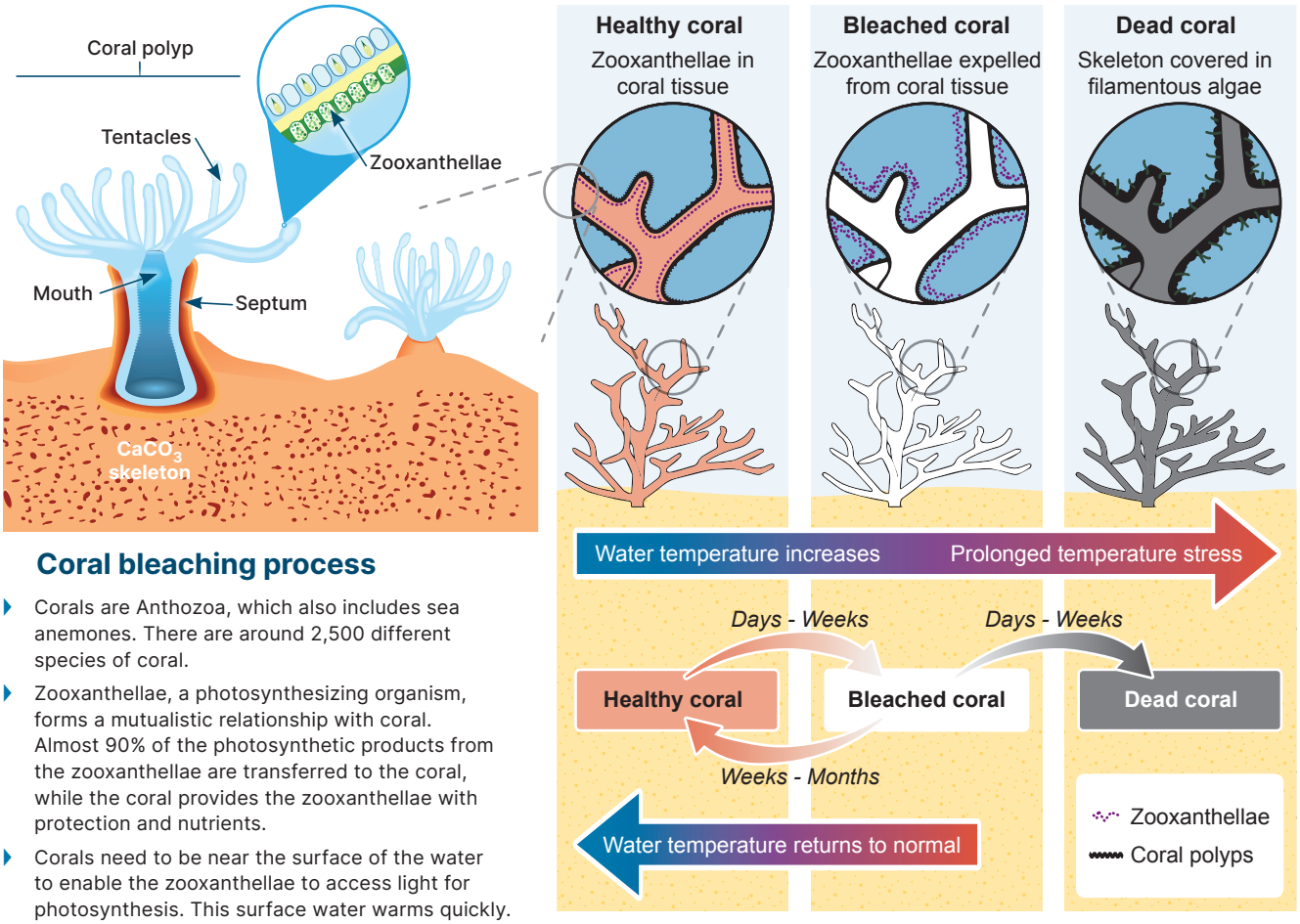

Coral bleaching process

- Corals are Anthozoa, which also includes sea anemones. There are around 2,500 different species of coral.
- Zooxanthellae, a photosynthesizing organism, forms a mutualistic relationship with coral. Almost 90% of the photosynthetic products from the zooxanthellae are transferred to the coral, while the coral provides the zooxanthellae with protection and nutrients.
- Corals need to be near the surface of the water to enable the zooxanthellae to access light for photosynthesis. This surface water warms quickly.
- Increased light and warmth increase the photosynthetic rate of zooxanthellae, overwhelming the coral polyps with waste material. The expulsion of zooxanthellae by the coral occurs as a stress mechanism to avoid tissue damage.
- The removal of zooxanthellae is called bleaching and the coral appears as a distinctive white color. This is because the zooxanthellae pigments give the coral their bright colors.
- Corals can survive in a bleached state for only a limited number of weeks and starve without the zooxanthellae.

Coral bleaching as a tipping point

Climate scientists project that around 70-90% of warm water corals will be lost once the global temperature threshold reaches 1.5°C for a sustained period. Around 99% of corals will disappear at just half a degree more.

Some corals are resilient and the zooxanthellae can return once ocean waters cool. However, once enough coral has died because of prolonged temperature stress, a tipping point will be reached where the coral ecosystem will fail to recover. Coral will not reproduce and spawn, therefore there will be no larvae to regenerate new coral colonies. The system will typically tip into a different algae dominated ecosystem.

4. Why does the death of the coral in an area often lead to a tipping point, while this is not necessarily the case with bleached coral?

5. Why are warm water corals particularly vulnerable to ocean temperature rise?

6. Observe the images of coral reefs on the previous pages. What are some observable differences between bleached and healthy coral? Discuss in pairs and note your ideas below:

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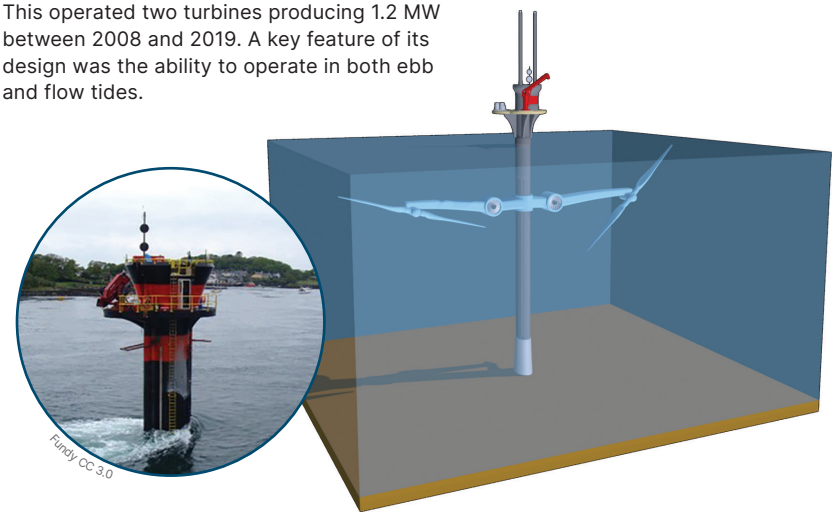
130 Ocean Power

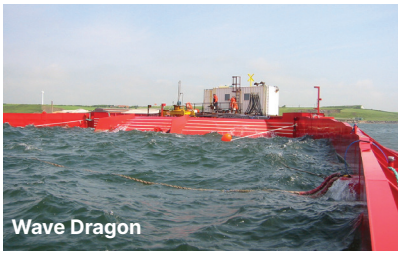
Key Idea: The energy in tides and waves can be used to provide a source of electricity, but designing equipment to withstand the sea is difficult.

An enormous amount of energy is stored in the world's oceans. Twice daily, tides move huge volumes of water up and down the coasts of the continents, while billions of joules of energy are transferred when waves meet the shore. Many of the world's energy problems could be solved if this energy could be harnessed, but many problems exist in doing this. Machinery to harness tidal or wave energy requires certain shoreline contours and seabed features, and regular swells. It must also be able to withstand constant immersion in seawater and the relentless and often unpredictable movement of the sea. Many designs have been proposed to exploit various types of seawater movement. While some have shown promise, most have not proved economically viable and concerns also exist over effects on marine life and shorelines. For these reasons, ocean power is unlikely to contribute much to future world energy needs.

Machines to harness tidal or wave energy

Underwater turbines use the simplest designs for harnessing tidal power use. These exploit the currents produced by tides. These operate in much the same way as wind turbines. The largest of these designs has been the SeaGen (below). This operated two turbines producing 1.2 MW between 2008 and 2019. A key feature of its design was the ability to operate in both ebb and flow tides.





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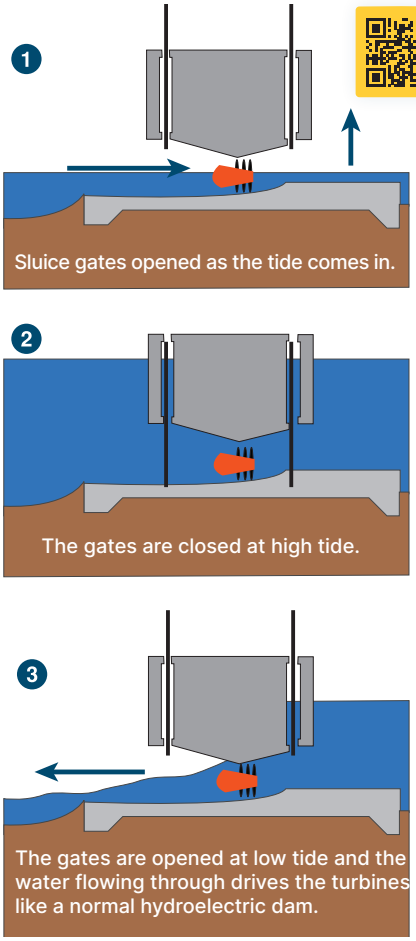
- **Wave power** as a means of electricity production is very complex. Developers must take into account wave height and period. These vary almost continuously, sometimes subtly and sometimes by extremes. Unlike many tidal power stations, wave powered systems need to withstand continual pounding by waves.
- Very few designs have proved economically viable or been able to operate for more than a few years. Pelamis was a promising, but ultimately uneconomic, design. Wave Dragon is still undergoing testing.

Tidal barrages require several meters of tidal difference and may negatively affect the estuaries across which they are built. The largest is the Sihwa Lake Tidal Power Station powerplant in South Korea with a output of 254 MW. It cost over $500 million to build.



1. Describe the technical problems associated with producing energy from the sea: _____

2. Describe the potential benefits of harnessing ocean power: _____

3. Explain why ocean power is unlikely to ever produce much of the world's energy: _____

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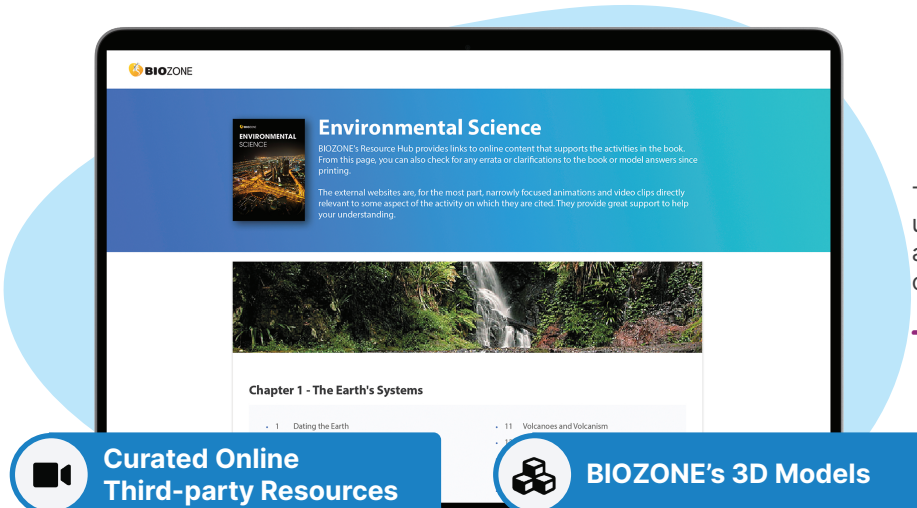

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The **Resource Hub** provides print book users with **FREE access** to curated material and resources which support the content of the worktext.

There is much to explore!

Curated Online Third-party Resources

Activities are supported with videos, animations, and weblinks.

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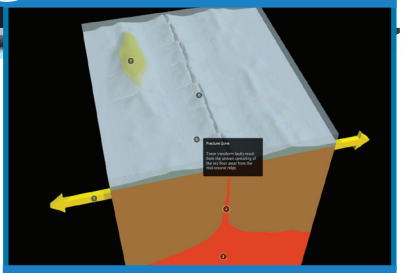

Interactive 3D models provide a fun way to engage students.

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Some activities feature QR Codes (links) to real-time data sources, especially relating to climate change.

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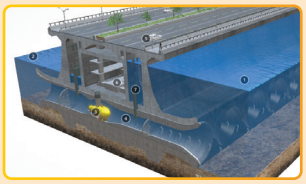

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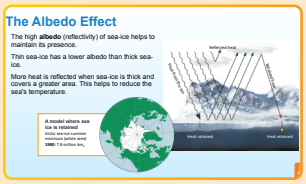

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