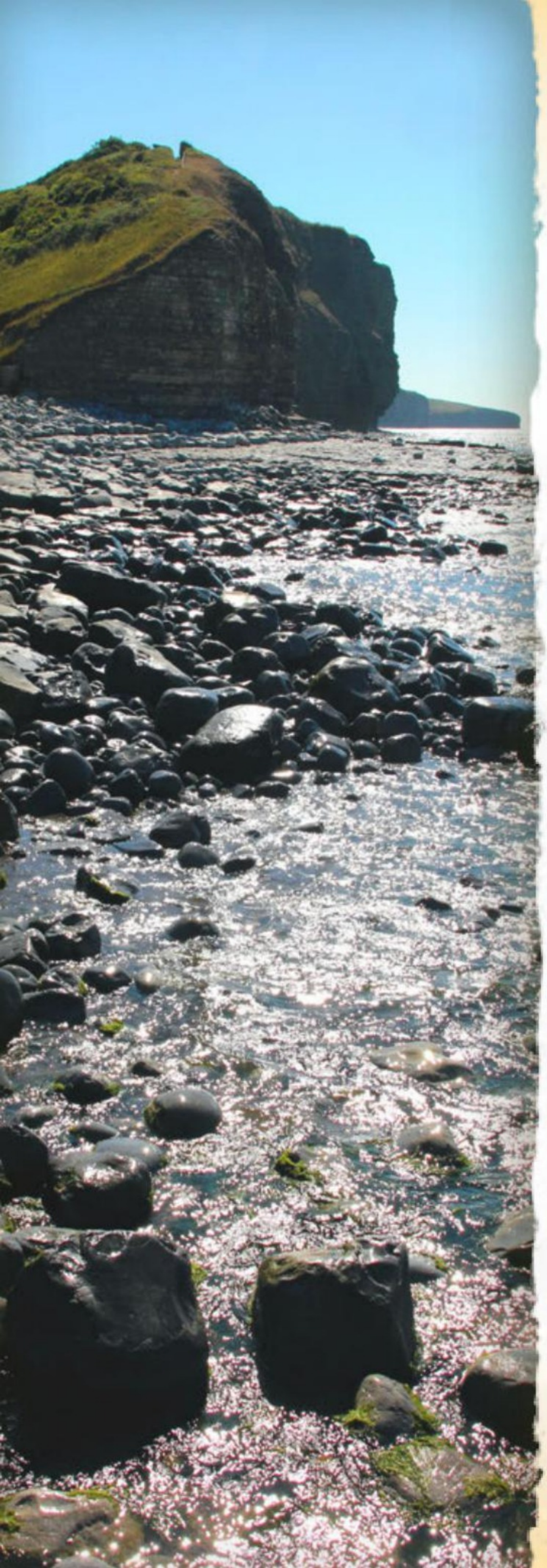

# Our Planet's Oceans and Coasts

PLANET GEOGRAPHY

E-BOOK

Stephen Codrington

Solid Star Press
Hong Kong

# Our Planet's Oceans and Coasts



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Cover photos show Llantwit Major Beach, South Wales, United Kingdom.

# Contents



# Photo
## Acknowledgements


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# Preface

*Our Planet's Oceans and Coasts* is one of seven monographs written to support the options for the International Baccalaureate Diploma Geography (IBDP) course. These seven monographs complement three larger books that span the entire content of the IBDP Geography Program. *Our Changing Planet* covers the SL and HL Core (Paper 2), *Our Connected Planet* covers the Higher Level Core Extension (Paper 3), and *Our Dynamic Planet* includes material on all seven options in the SL and HL themes (Paper 1).

As with all the books in the *Planet Geography* series, my aspiration is that every reader of this book will acquire knowledge and wisdom to become an effective steward of our planet, committed to ensuring its healthy survival and vibrant flourishing.

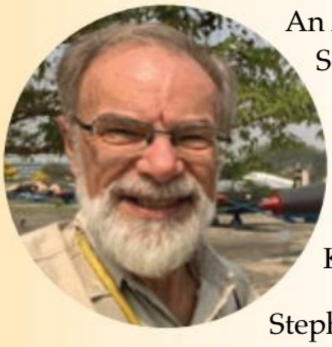
Any comments or suggestions to improve future editions of this book are always welcome. I hope you, the reader, will enjoy learning more about the geography of our fascinating planet as I have over the years.

Stephen Codrington.

# The Author

Dr Stephen Codrington has a Ph.D. in Geography, and has taught the subject in several countries at both the high school and university level. He is the author or co-author of 69 books, mainly books that focus on his life-long passion for Geography.

Following his highly successful career as a teacher of Geography and Theory of Knowledge, including serving as the Head of five International Baccalaureate (IB) schools in four countries, he now works with school boards and leaders through Optimal School Governance, educates trainee teachers at Alphacrucis College, and is Chair of the Board at Djarragun College.



An Australian by birth, Stephen is a former President of both the Geographical Society of New South Wales and the Geography Teachers' Association of New South Wales (twice). He edited Geography Bulletin, the journal of the Geography Teachers' Association of New South Wales for seven years, and is now a Councillor and Treasurer of the Geographical Society of New South Wales. He has taught in schools in Australia, the United Kingdom, New Zealand, Hong Kong and the United States.

Stephen has been honoured with election as a Fellow of the Australian College of Education, the Royal Geographical Society (UK), and the Geographical Society of NSW. He was appointed to the role of IB Ambassador in 2014 and honoured with life membership of the Geographical Society of New South Wales in 2018. He is a former Chairman of HICES (Heads of Independent Co-educational Schools). Stephen's work has taken him to 161 countries, and he has been listed in Who's Who in Australia every year since 2003.

From 1996 to 2001 he served as Deputy Chief Examiner in IB Diploma Geography, setting and marking examination papers, assisting with curriculum development, and leading many teachers' workshops.

He maintains a personal website at www.stephencodrington.com that contains links to travel diaries and other items of geographical interest.

# Chapter 1 Ocean-atmosphere interactions

**1.1** Oceans cover more than 70% of the earth's surface, and their interaction with the atmosphere is essential for our planetary processes. This view looks out towards the Pacific Ocean from Bahia de los Piratas, Costa Rica.

## Ocean currents

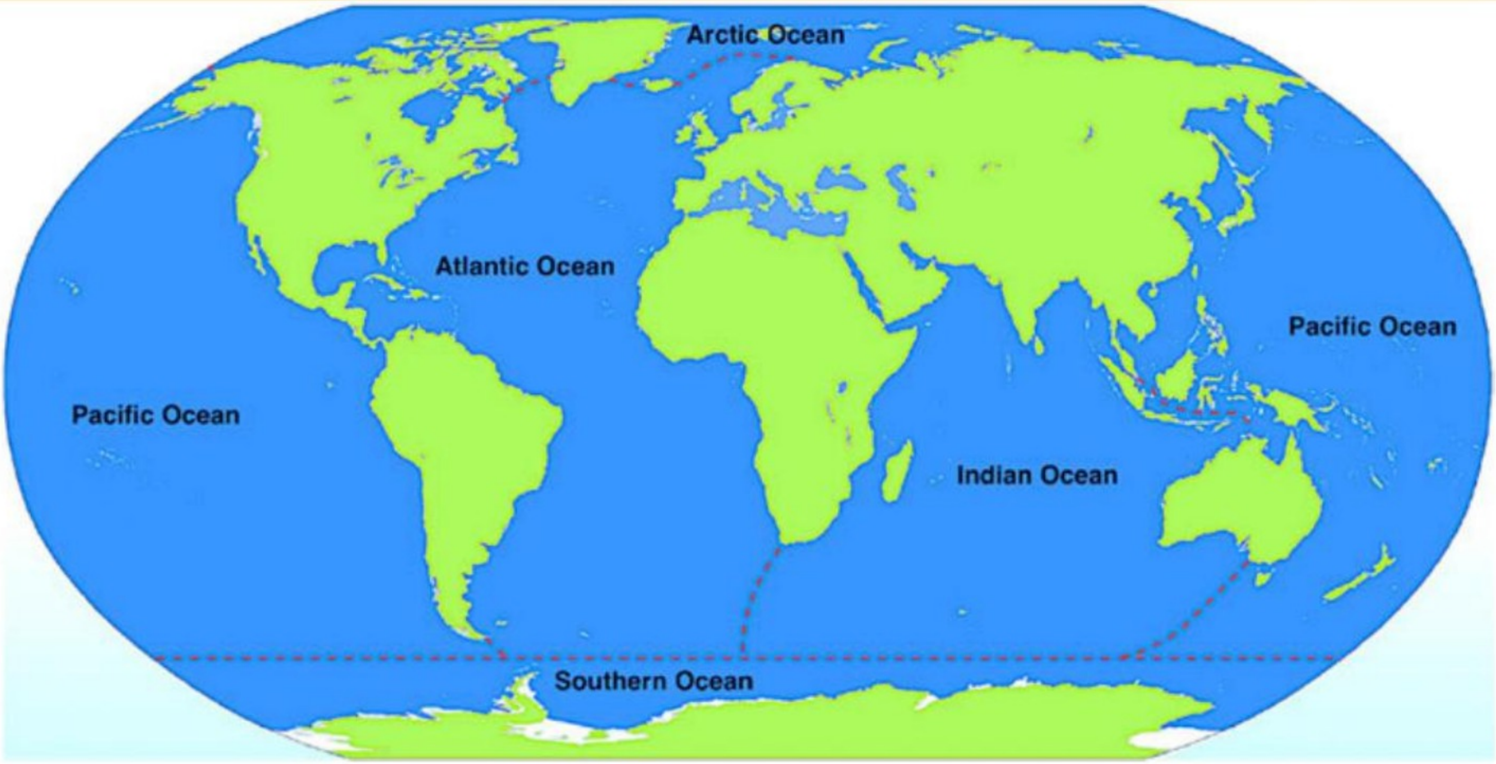
### Distribution of oceans

About **71%** of the earth's surface is covered by water. Although some of this area comprises lakes and seas, most of the 71% consists of the **five interconnected oceans**, these being the Arctic, Atlantic, Indian, Pacific and Southern Oceans. The boundaries that separate the oceans from each other are somewhat arbitrary and blurred, but the general limits of each of the oceans is shown in figure 1.2.

The **size** of the oceans varies markedly, and when ranked from the largest to the smallest, the list is:

- Pacific (155,557,000 square kilometres)
- Atlantic (76,762,000 square kilometres)
- Indian (68,556,000 square kilometres)
- Southern (20,327,000 square kilometres)
- Arctic (14,056,000 square kilometres).

Sometimes, the five oceans are collectively referred to as the **world ocean**. This is because the divisions are imaginary rather than real and the water from each ocean mixes with water from the others at various points.




1.2 The location and extent of the world's five oceans. The red dashed lines represent approximate edges, not precise boundaries.

The world's oceans hold a vast quantity of water, a volume that has been estimated to be 1.185 billion cubic kilometres. This amounts to **97.3%** of all the water on the planet.

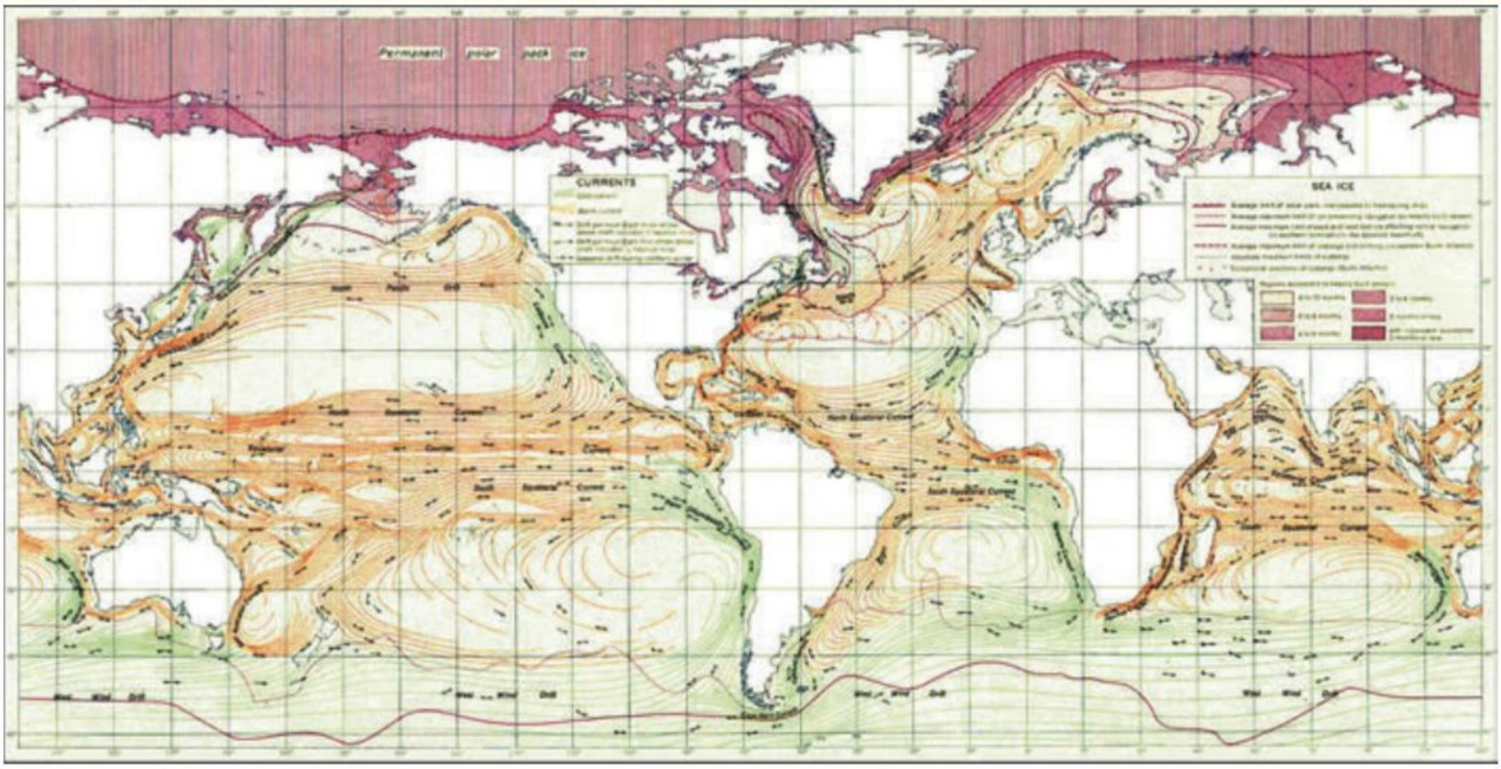
The **chemical composition** of the water in each of the oceans is very similar from place to place, but varies very little from year to year. In fact, we can think of the oceans as being a single giant chemical mixing tank. There is an **inflow** of water and chemicals (in the form of dissolved minerals and materials) from the world's rivers, glaciers, rain and wind. There is also a smaller but very important input of **chemicals** from the hydrothermal (hot water) reactions between the sea water and hot basalt rocks that ooze to the surface along the mid-ocean ridges along the bottom of some of the world's oceans.

Balancing these inputs to a large extent, the oceans are continually **losing water** from their surfaces to the atmosphere by **evaporation**, and this loss almost precisely matches the various inputs of water. The dissolved components of the sea water all contribute to various **chemical** and **biological** reactions that eventually cause them to **precipitate** out of the sea water onto the ocean floor. This is why the ocean's **salinity** remains constant over time. Overall, the precipitation of chemicals from the ocean waters to the ocean floors equals the total inputs of all dissolved materials from weathering on the continental land masses plus the hydrothermal activity at the ocean ridges.

The reason that the composition of all the oceans is similar is that there is a general pattern of **circulation** of water between the oceans. Water moves in a constant pattern of clockwise and anti-clockwise movements through ocean currents which flow like giant rivers through the oceans.

The general pattern of **ocean currents** is shown in figure 1.3, which is based on a United States Army map compiled in 1943; being a US-centric map means that the Pacific Ocean circulation can be seen clearly compared with the more common Euro-centric maps that split the Pacific Ocean (figure 1.2).

The ocean currents can be seen to comprise five major ocean-wide **gyres** (a term that means a swirl, spiral or vortex). The two gyres in the northern hemisphere (one in the North Atlantic and one in the North Pacific) spiral in a clockwise direction, while the three gyres in the southern hemisphere (Southern Atlantic, Southern Pacific and Indian Ocean) spiral anti-clockwise. The reason for this difference in the **Coriolis Force**. The Coriolis Force results from the earth's rotation, and it causes all moving objects in the northern hemisphere to be deflected to the right while moving objects in the southern hemisphere are always deflected to the left.




**1.3** The world's ocean currents, as shown on a 1943 US military map. Warm ocean currents are shown in orange, cool currents are shown in green, and areas of sea ice are shown in red.

**Ocean currents** occur because there is very little **friction** between the ocean waters and the solid earth. Therefore, as the earth rotates, the water moves differently to both the solid crust beneath and the lighter atmosphere above. The **speed** of ocean currents varies according to depth, but in general, currents near the **surface** of the oceans move at speeds of about 9 kilometres per hour. On the other hand, **deep** currents move much more slowly at speeds of about 1 kilometre per hour.

As currents move through **equatorial areas**, the water becomes **warmer**. In the same way, ocean currents **cool** as they flow in **polar areas**. Therefore, ocean currents flowing along a coast from equatorial areas will bring warm water, while flowing from polar areas will bring cooler water. This is shown in figure 1.3, where warm ocean currents are shown in orange while cool ocean currents are shown in green.

**1.4** The Atacama Desert extends all the way to the coastline of the Pacific Ocean in northern Chile due to the influence of the cold ocean current in the area. In this view, the dunes of the Atacama Desert tower above the coastal city of Iquique.

Because of the clockwise and anticlockwise movements of the currents, continents in both hemispheres tend to experience **warm currents** on their **eastern** sides and **cool currents** on their **western** edges. Warm ocean currents tend to bring more rain than cold currents, and this helps to explain why many deserts are found on the western sides of continents, as seen in Australia, Namibia, Chile, California and Morocco.

## Question Bank 1A

1. *Using the data in this section, calculate the percentage of ocean water found in each of the five oceans.*
2. *Explain why the chemical composition of the oceans remains fairly constant over time.*
3. *Describe and account for the pattern of the world's ocean currents. Relate this pattern to the ocean-wide gyres.*
4. *Outline the impact of ocean currents on the climatic differences between the eastern and western sides of the continents.*

## Morphology of oceans

As long ago as 1620, when the shapes of the continents were still being charted, geographers were commenting on the similarities between the shapes of the east coast of South America and the west coast of Africa. Some people suggested that the continents may have been joined at one time, later splitting and '**drifting**' apart. At first, people who made this suggestion were not taken very seriously.

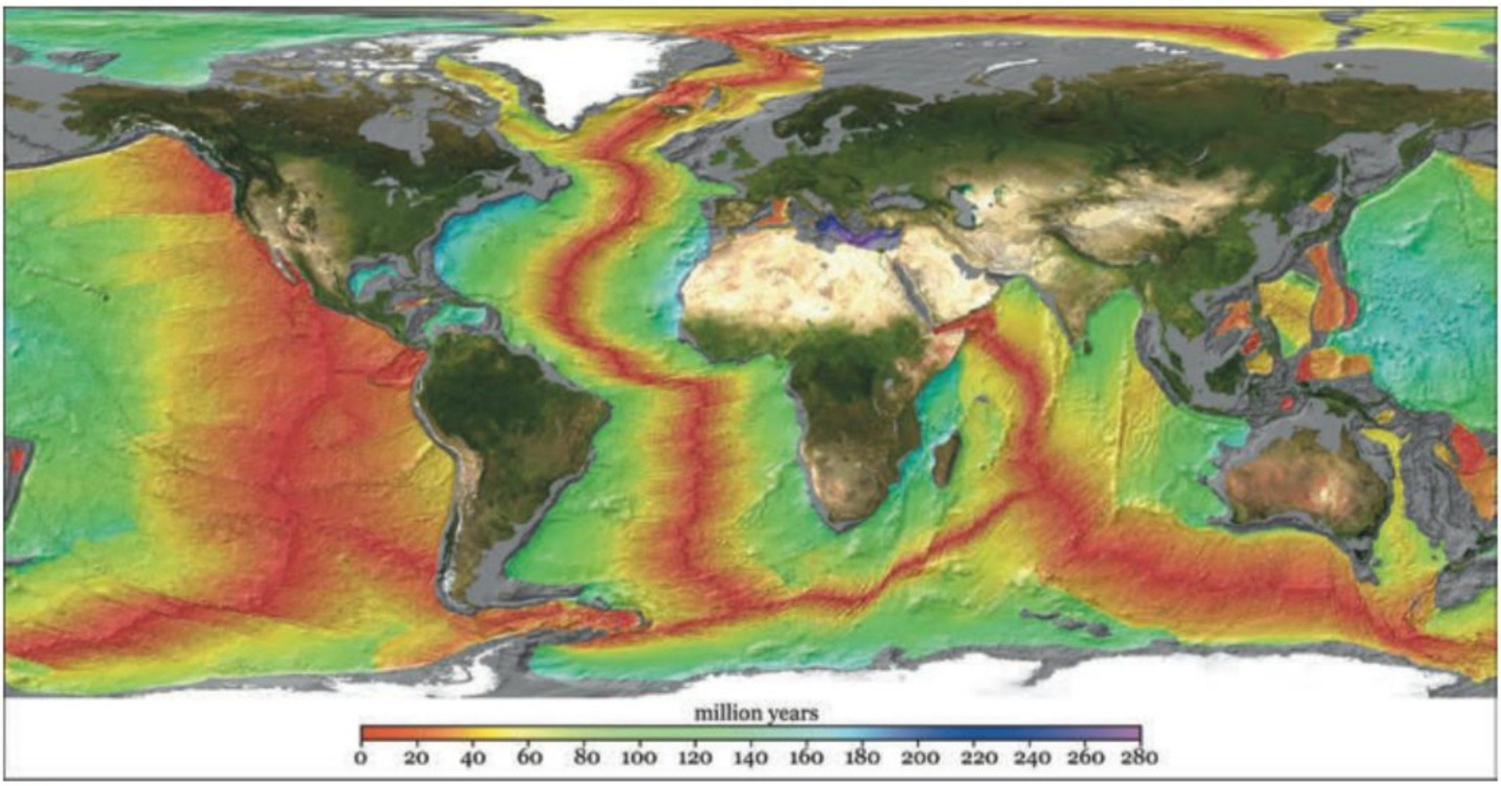
Geographers were determined to explain the shapes of these coastlines, because they seemed too similar to be a coincidence. Research was undertaken, and it was discovered that **rock strata** which crossed into the sea in West Africa seemed to continue on the east coast of South America, like a perfect match of two jigsaw pieces that had become separated. Other similarities were also observed, such as common types of **plants** and **landforms**, and eventually it was agreed that Africa and South America had once been joined together. Like many discoveries, this 'answer' raised many more questions, such as 'how did the continents move apart?'.

The answer to the puzzle lay in the **morphology** (shape) of the ocean floor. The main features of the ocean floor may not be as well known as the mountain chains of the continents, but they tell us a great deal about the way the planet was formed. The shape of the ocean floors can be seen in figure 1.5. In this figure, the age of the ocean floor has been coloured to indicate the age of the rocks. Red indicates the **youngest** rocks, with yellow and green representing **older** rocks, through blue and purple to the **oldest** rocks. Ocean areas shown as grey are shallow continental shelves covered with recent sediments.

Figure 1.5 shows clearly that the **youngest rocks** are found in lines along the ocean beds. This suggests that the ocean morphology arises from **tectonic processes**, which means they relate to the large-scale forces that build the earth's structure.

The earth's crust consists of a number of large **plates**, also known as **crustal plates** or **tectonic plates.** These plates move slowly, driven by currents in the liquid mantle beneath. New crustal material comes up to the surface from the mantle beneath at the mid-ocean ridges, such as the Mid-Atlantic Ridge that can be seen clearly in figure 1.5.

The **mid-ocean ridges**, where new surface rocks are being formed, are known as **constructive** plate margins. In other parts of the world, plates collide and crustal material is destroyed, either by being forced downwards into the mantle (in which case it




1.5 The shape of the ocean floor, coloured to indicate the ages of the rocks. For details, see the text above.

is known as a **subduction** zone), or by crumpling upwards to form mountain ranges. Such plate margins are known as **destructive** plate margins.

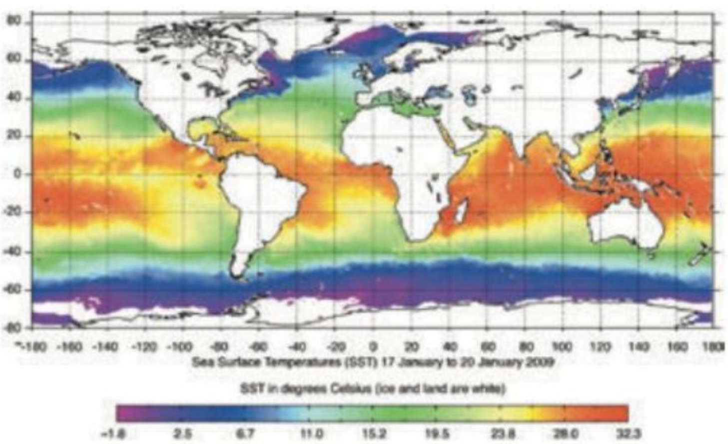
Deep **ocean trenches** may form along the subduction zone where the two plates are forcing each other downwards into the mantle. Some of these trenches are extremely deep, and they typically extend three to four kilometres below the surface of the ocean. The deepest ocean trench and thus the lowest point on the planet is thought to be a point in the Mariana Trench off the east coast of the Philippines which is 10,920 metres below sea level.

### QUESTION BANK 1B

1. *Explain the pattern of colours shown in figure 1.5.*
2. *Explain how ocean trenches are formed, and why they they are so deep.*

## Oceanic water

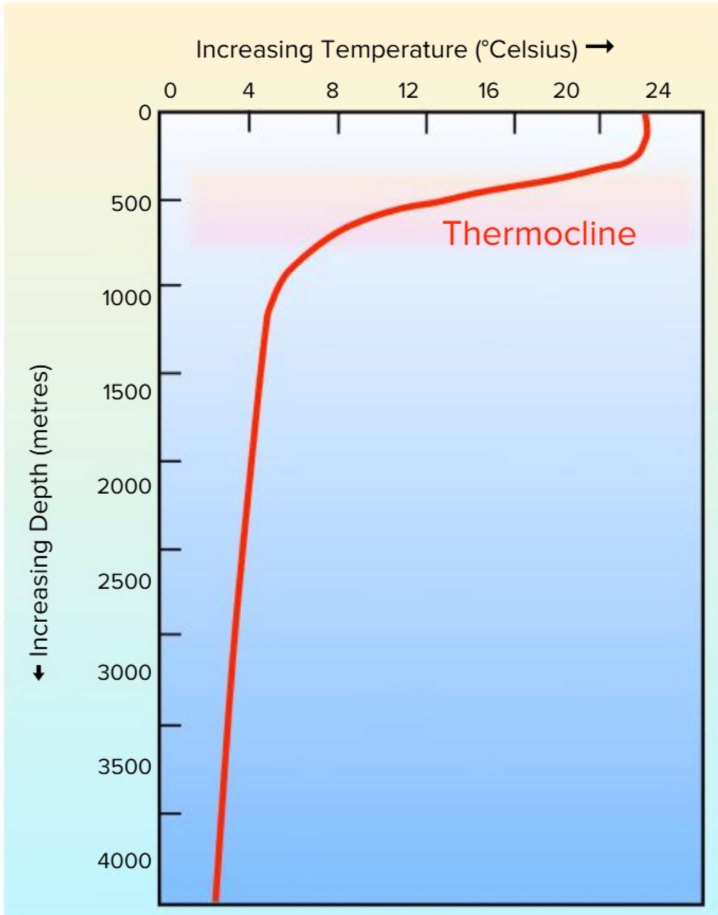
As anyone who has tried swimming in winter as well as summer will testify, the temperature of the ocean is not always constant. Ocean **temperature** not only **varies** through the **seasons**, but by **latitude**. Waters near the equator are warmer than ocean temperatures towards the poles. This can be seen in figure 1.6, which shows sea surface temperatures (SSTs) during a typical northern hemisphere summer. Although we talk about sea surface temperatures, these are usually recorded remotely by satellites that are tuned to detect temperatures one metre below the surface.




**1.6** Sea surface temperatures during a typical northern hemisphere summer. Computerised digital image used courtesy of the National Geophysical Data Centre, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, http://www.ngdc.noaa.gov/.

The impact of the **ocean currents** discussed earlier can be seen clearly in figure 1.6. On the western sides of the continents, the cooler waters from ocean currents can be seen intruding towards the equator. Similarly (if not quite so clearly), the warmer waters of ocean currents flowing from the equatorial regions can be seen on the eastern sides of several continents.

As we would expect, ocean water also varies considerably with **depth**. Two of the significant variations with depth are **temperature** and **salinity**. Ocean waters vary in temperature between summer and winter down to a depth of between 500 and 1000 metres. Below that level, the rate of temperature decline is much slower. Figure 1.7 shows a fairly typical example of the relationship between water temperature and ocean depth where temperature decreases with increasing depth.

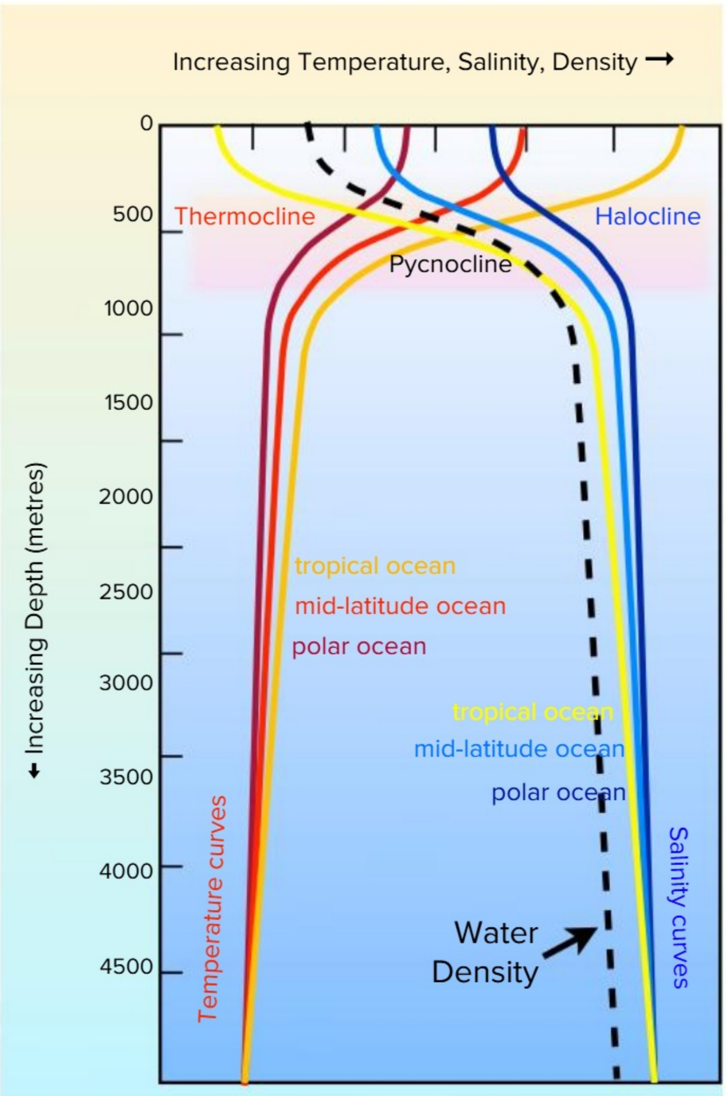



**1.7** The relationship between ocean temperature and water depth in the mid-latitudes.

A **boundary** usually occurs at a depth of between 200 and 800 metres called the **thermocline**, below which the surface waters do not mix with the deeper layers. This boundary region is marked by a rapid decrease in temperatures as depth increases.

About 90% of the total volume of ocean water is found below the thermocline, and in these deeper waters, the temperatures approach 0°C.

Other changes also occur as depth increases. For example, the **density** of ocean water increases constantly with decreasing temperature until the water freezes. Because ocean water is saline (salty), its normal **freezing** temperature is -1.94°C, a significant difference from the freezing point for pure water, which of course is 0°C. In the polar regions, it is quite common for water to reach -1.94°C and therefore turn to ice. As it does so, some of the **dissolved salts** in the water are usually rejected by the ice that is forming, and therefore sea ice is only about 1% salt whereas normal sea water is about 3.5% saline. For this reason, sea ice is usually safe for humans to consume even though sea water is not.




1.8 The relationship between water temperature, salinity, water density and depth of the ocean in tropical, mid-latitude and polar regions of the world.

Salinity and density show the **opposite trend** to water as the depth of ocean water increases. Temperature **declines** with increasing depth, but salinity and water density both **increase**. In the same way that temperature shows a rapid fall at the thermocline, salinity shows a rapid increase at about the same depth, which is referred to as the **halocline**. Because temperature declines as salinity increases, the net effect is to **increase water density** as depth increases. Because the thermocline and the halocline occur at about the same depth, the water density also increases most rapidly in the same zone, which can also be referred to as the **pycnocline**, which is defined the layer in the ocean where the water density increases rapidly with depth.

These changes are seen **more sharply** in tropical areas than polar areas because the surface temperatures are warmer in equatorial areas than near the poles. At great depths, the temperature of ocean water shows very little difference between the equator and the poles. The relationships described are shown in a simplified graphical way in figure 1.8.

### QUESTION BANK 1C

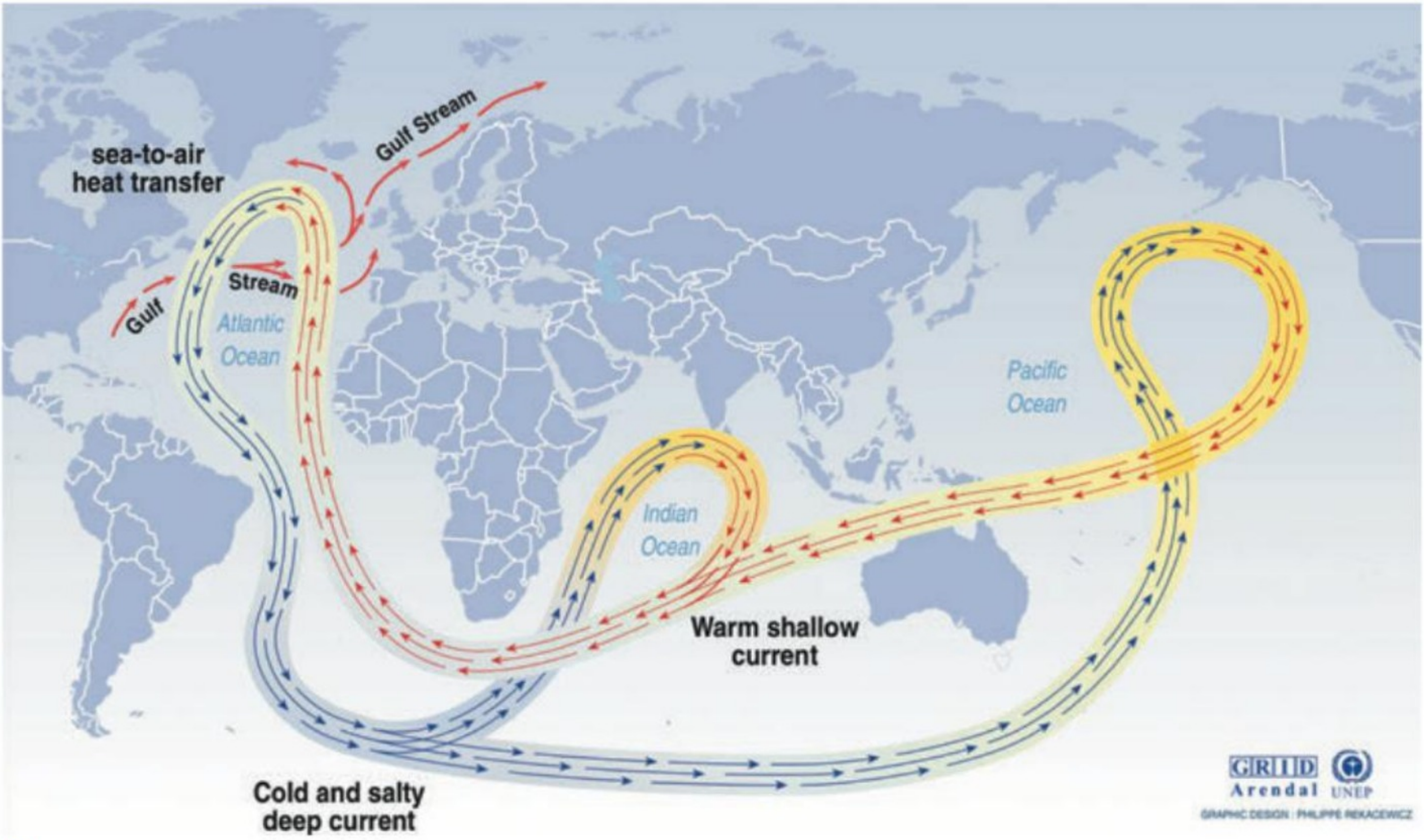
1. *Describe the pattern of sea surface temperatures shown in figure 1.6.*
2. *What is the relationship between the thermocline, the halocline and the pycnocline?*
3. *Describe and account for the information shown in figure 1.8.*

# Atmosphere-ocean interactions

## Nutrient and energy transfers

The water in each ocean mixes with water from the other oceans at various points. The way in which this happens is a global-scale movement called the **thermohaline circulation** (THC), sometimes referred to as the **oceanic conveyor belt**. The path of the THC is shown in figure 1.9.

The starting point for the thermohaline circulation is usually thought of as the warm, salty surface ocean water from the **Gulf Stream**. The Gulf Stream is a current of warm water that flows from




1.9 The thermohaline circulation, or oceanic conveyor belt. Courtesy: Grid Arendal and UNEP, graphic design by Philippe Rekacewicz.

the Caribbean across the Atlantic Ocean to the western coast of Europe. When it reaches the cold, polar conditions of the North Atlantic Ocean, the water becomes **chilled** and increases in **density**. The chilled surface water **sinks** in the North Atlantic and then flows south near the **bottom of the ocean** towards Antarctica. When it reaches the Antarctic, the water is cooled even more and flows north at the bottom of the oceans into the Indian, and Pacific Ocean basins. As it approaches the equatorial areas of the Indian and Pacific Oceans, the water **warms** and becomes **less dense**, and therefore rises towards the surface, returning as **surface flow** to the North Atlantic Ocean. It takes water **almost 1,000 years** to move through the entire cycle of the thermohaline circulation.

The changes to the thermohaline circulation are shown in figure 1.9 by the different colours of the arrows. **Cold water** flowing at great depths is shown by the blue arrows, while **warmer surface flows** are indicated by red arrows. Waters that are **dense** due their cold temperatures and high saline concentrations are shown as blue and green belts. On the other hand, the yellow and orange belts indicate flows that are **lighter in density** because they are warmer and less saline.

The THC represents much more than a slow flow of density-driven water. As the thermohaline circulation flows at great depths near the bottom of the ocean, the water becomes enriched with important **nutrients** such as phosphates, nitrates, silicates and dissolved carbon dioxide. These minerals are then **distributed** through all the oceans by the THC, reducing the physical and chemical differences between them and making the world's oceans a **single global system**.

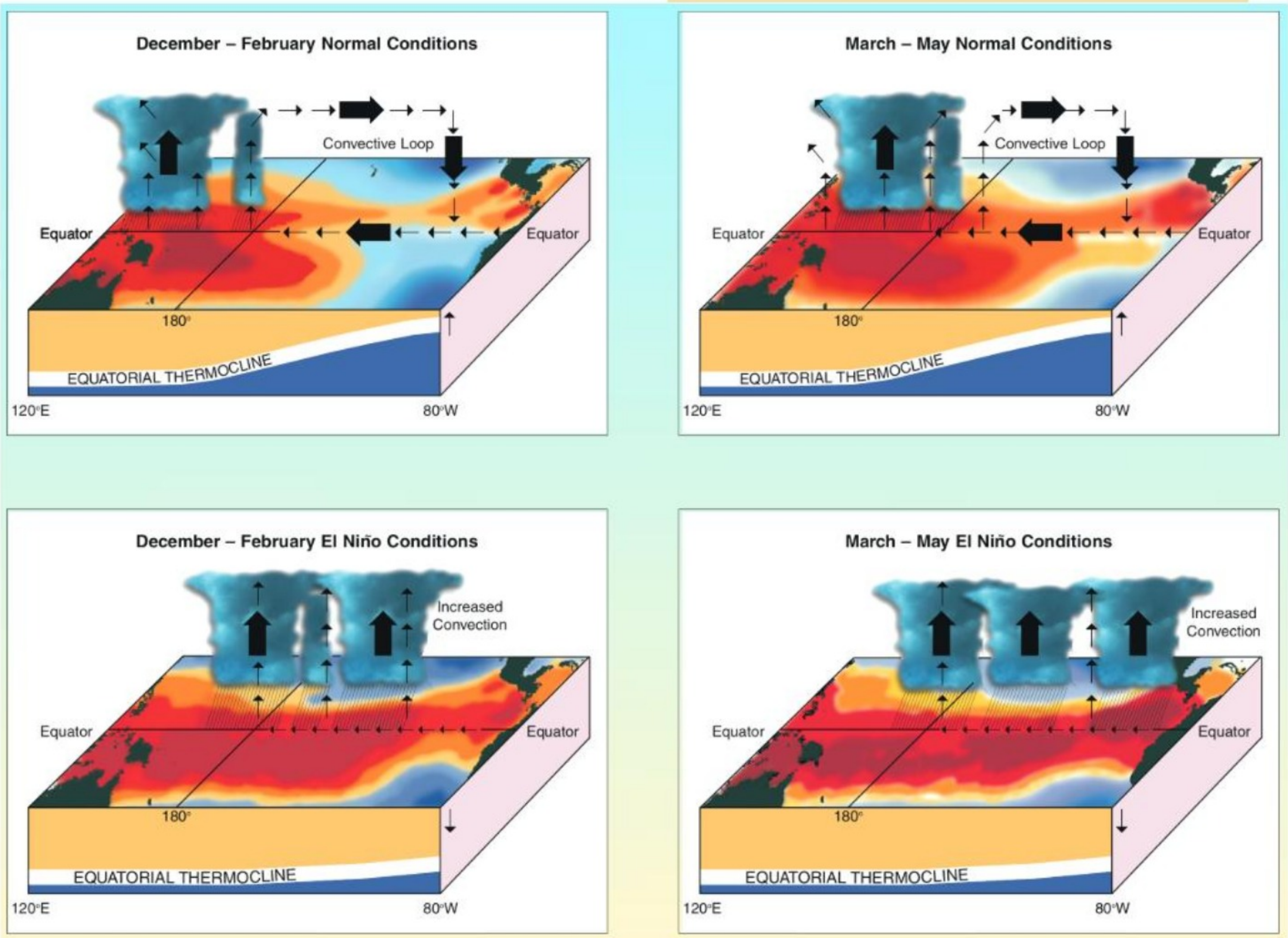
In addition to redistributing minerals, the thermohaline circulation also moves **energy** (in the form of heat) around the globe. In brief, the thermohaline circulation moves **heat** from equatorial regions to the polar regions, and therefore plays an important role in controlling the quantity of sea ice near the poles. Some researchers claim that it is changes in the thermohaline circulation rather than climate change which are influencing the size of the **polar ice caps**. Other researchers suggest that **global warming** is itself an important factor affecting the density of the ocean's surface water, and as the flow of the THC is density-driven, this is the main factor in altering the circulation of the THC.

The **rate of flow** of the thermohaline circulation governs the rate at which deep waters are brought to the surface and exposed to the atmosphere. As the $CO_2$-rich THC is a source of adding carbon dioxide into the atmosphere, its rate of flow is an important factor in determining the **concentration of carbon dioxide** in the atmosphere. This in turn is important in analysing the rate of global warming as carbon dioxide is one of the more important greenhouse gases.

We can therefore say that the THC and global temperatures are **interdependent**, as each has the potential to influence the other.

## Question Bank 1D

1. *The Gulf Stream is powered by the wind and flows at an average speed of 6.5 kilometres per hour. Using this information, compare the speed of wind-generated ocean currents and the density-driven thermohaline circulation.*
2. *What is meant when we say that the thermohaline circulation is 'density-driven'?*
3. *In what ways does the thermohaline circulation transfer energy and nutrients around the world?*
4. *What role do the oceans play as a store and source of carbon dioxide.*
5. *What evidence is there to support the claim that 'the thermohaline circulation and global temperatures are interdependent'?*




**1.10** Normal vs El Niño conditions. The colours represent ocean temperatures, with 'hotter' colours representing warmer temperatures. The two top diagrams show normal (not El Niño) conditions. Under normal conditions, a convection cell in the atmosphere is driven by heat at the ocean surface. Water from the warm surface evaporates and rises in the western Pacific, pulling in cool, dry air from South America. This creates a loop (cell) spanning the Pacific with easterly winds at the surface and westerly winds at high altitude, transferring heat and moisture out of the hot zone in the western Pacific. Cool water from the ocean depths near South America is drawn upwards to replace the surface water that has been moved to the west by the convection cell. The two lower diagrams show an El Niño event. During this time, the hot spot in the ocean moves to the east, creating two or three convection cells and altering climates around the Pacific basin (as shown in figures 1.11 and 1.12).

## ENSO cycles - El Niño and La Niña

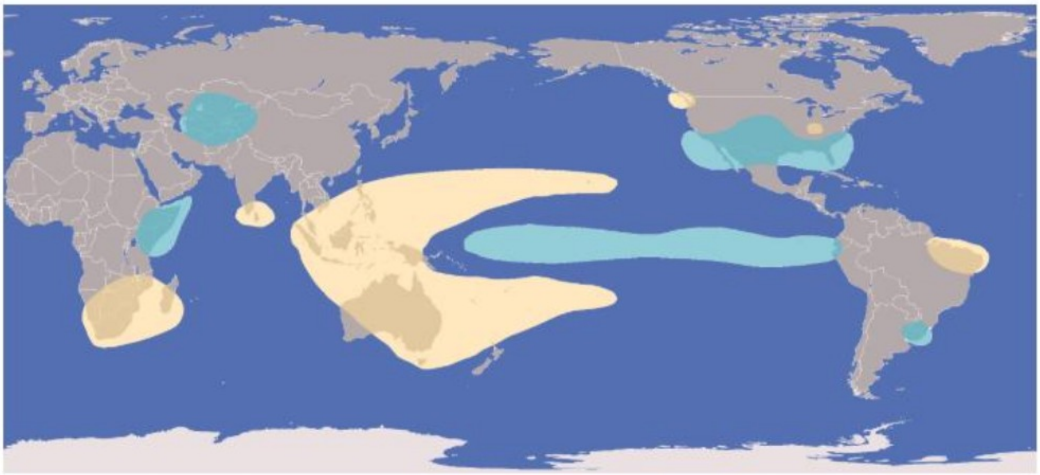
The term **El Niño** translates from the Spanish meaning 'the boy child'. It is a term that has been used for many years by Peruvians who fish for anchovy in the eastern Pacific Ocean. They referred to **a warm ocean** current that appeared off the coast of Peru, Ecuador and Chile each year at about Christmas time – hence the reference to the Christ child. The fishers noticed the arrival of the warm current because it replaced the **nutrient-rich cold current** that usually flowed along the coast, thus reducing the food supply for the anchovy. When the warm current was especially strong, it ruined the anchovy harvest and caused economic ruin to the fishers.

The term El Niño has now been broadened, and it refers to the **significant warming** of the water that occurs every few years in the Pacific Ocean. These El Niño events are significant because they have an impact on **global weather** and climate patterns.

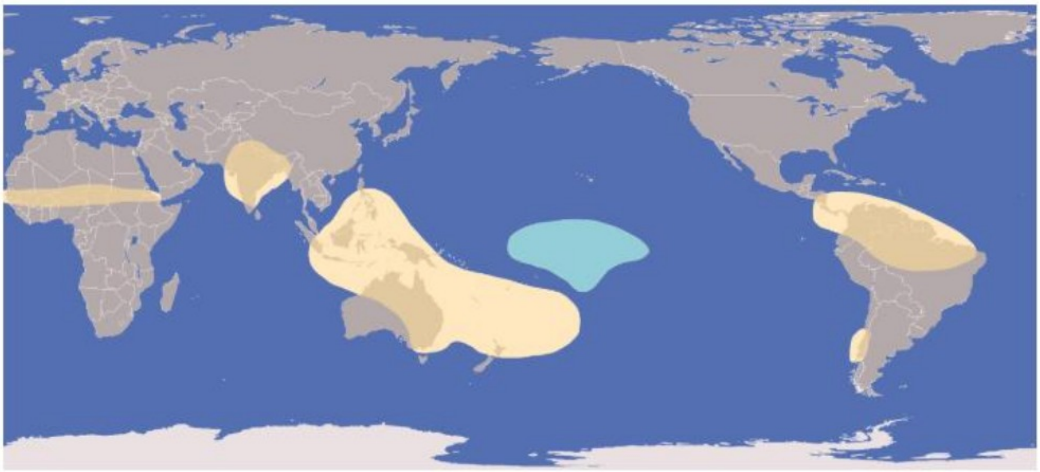
In **normal** conditions when El Niño is not operating, the waters off the west coast of South America (near Peru and Ecuador) comprise **cold water** that is rich is nutrients. This cold water is brought up from the ocean depths to replace surface water that has been driven west by prevailing winds.

Because the waters near the South American coast are cooler than the waters further west in the Pacific Ocean, a giant convection cell forms in the atmosphere over the Pacific Ocean. Known as the **Walker Circulation**, air **descends** over the **cool oceans** near South America, and **rises** over the **warmer oceans** near Australia, New Guinea and Indonesia (figure 1.10, top left). This situation usually exists during the southern hemisphere's summer and autumn period – from December to May each year.

During an **El Niño event**, the normal situation **reverses**. The warm ocean current moves to the east, closer to the South American coastline. The atmospheric convection cell follows the warm water, altering the entire pattern of wet-and-dry weather in the Pacific (figure 1.10, bottom left, and figures 1.11 and 1.12). In a prolonged El Niño event that extends through to March, April and May, the warm water moves even further east, bringing **heavy rains** to South America and **drought** to eastern Australia – the opposite of the 'normal' situation (figure 1.10, upper right and lower right).



1.11 Typical changes in rainfall during El Niño conditions in December-February. Blue areas receive more rainfall than normal; yellow areas receive less rain than normal (drought).



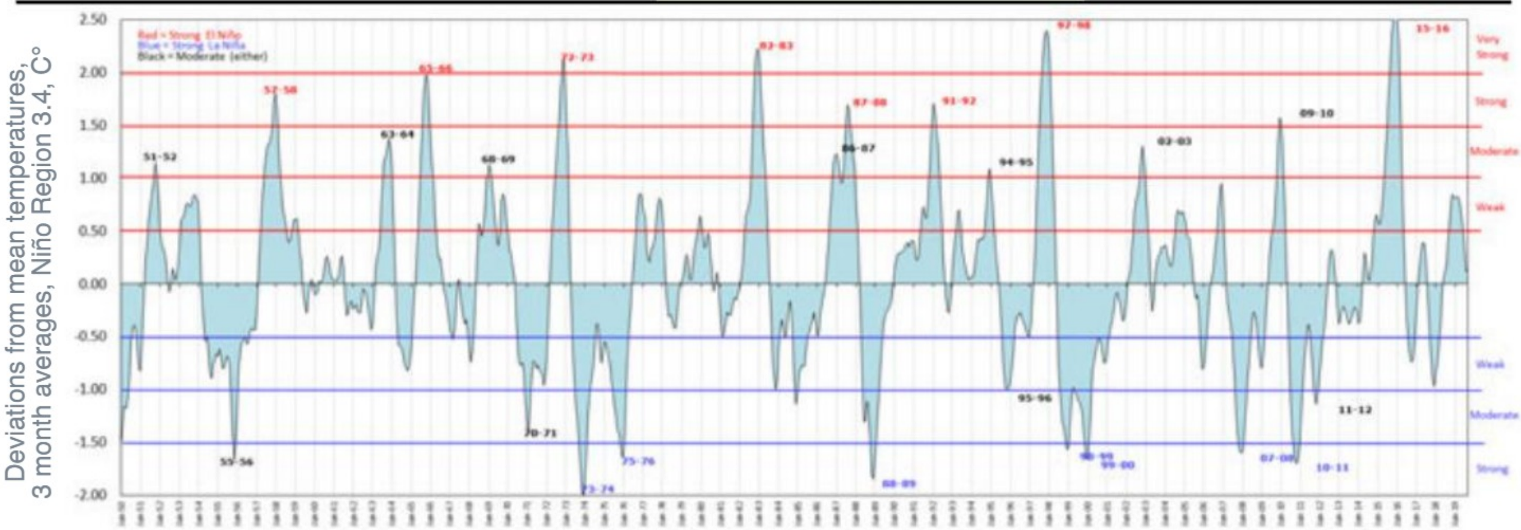
1.12 Typical changes in rainfall during El Niño conditions in June-August. Blue areas receive more rainfall than normal; yellow areas receive less rain than normal (drought).

During an El Niño event, the cool waters that are usually brought to the ocean surface near South America remain at a **deeper level**, allowing the surface waters to become warmer (figure 1.10, bottom). In other words, the permanent thermocline in the tropical waters of the Pacific Ocean lies at a deeper level than normal, during an El Niño event.

Table 1.1

A selection of past El Niño and La Niña events

| Warm ENSO Phase | | | | | | Cool ENSO Phase |
|---|---|---|---|---|---|---|
| **Very strong El Niño Events** | **Strong El Niño Events** | **Moderate El Niño Events** | **Weak El Niño Events** | **Weak La Niña Events** | **Moderate La Niña Events** | **Strong La Niña Events** |
| 1982-83 | 1957-58 | 1951-52 | 1951-52 | 1950-51 | 1955-56 | 1973-74 |
| 1997-98 | 1965-66 | 1963-64 | 1953-54 | 1964-65 | 1970-71 | 1975-76 |
| 2015-16 | 1972-73 | 1968-69 | 1958-59 | 1971-72 | 1995-96 | 1988-89 |
| | 1987-88 | 1986-87 | 1969-70 | 1974-75 | 2011-12 | 1998-99 |
| | 1991-92 | 1994-95 | 1976-77 | 1983-84 | | 1999-00 |
| | | 2002-03 | 1977-78 | 1984-85 | | 2007-08 |
| | | 2009-10 | 1979-80 | 2000-01 | | 2010-11 |
| | | | 2004-05 | 2005-06 | | |
| | | | 2006-07 | 2008-09 | | |
| | | | 2014-15 | 2016-17 | | |
| | | | 2018-19 | 2017-18 | | |




**1.13** Oceanic Niño Index (ONI), 1950-2019. El Niño events are the upward spikes, with strong El Niño events identified in red. La Niña events are the downward spikes, with strong La Niña events identified in blue.

Source: Based on NOAA data, with analysis by Golden Gate Weather Services

Wherever the equatorial updraughts occur in the Walker Circulation, intense **thunderstorms** are experienced. These thunderstorms release enormous amounts of heat energy that affect the circulation of the earth's atmosphere. Therefore, whenever the thunderstorms are shifted from their normal position, such as during an El Niño event, the **global circulation** of the atmosphere is altered.

El Niño can therefore be thought of as a **combination** of atmospheric and ocean processes.

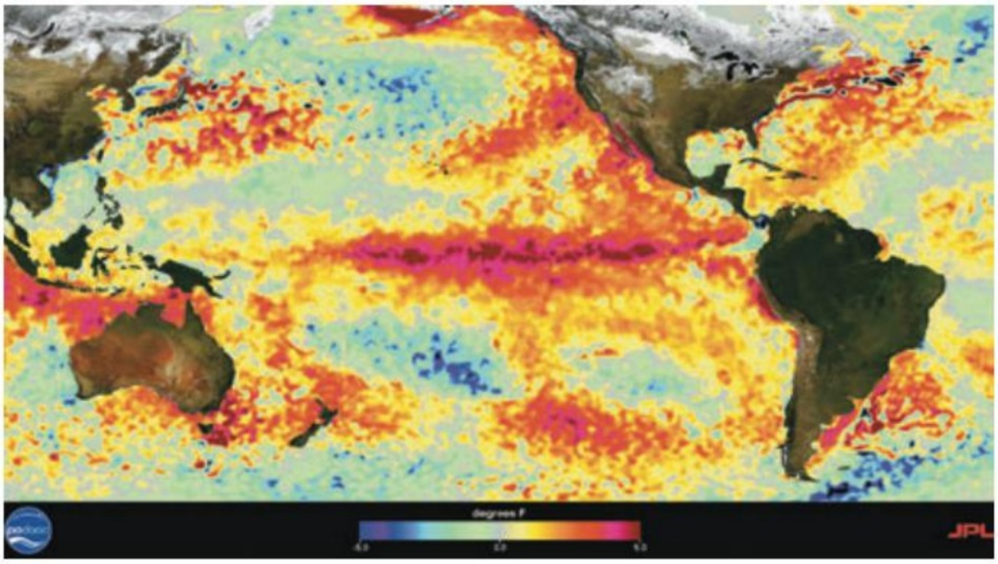
The atmospheric component of El Niño is called the **Southern Oscillation**, and when the atmosphere and ocean collaborate together, **ENSO** is said to occur, short for El Niño-Southern Oscillation.

An El Niño event corresponds to the **warm phase** of ENSO. The opposite can also occur, in which the tropical waters of the Pacific Ocean become cooler, and a **cold phase** of ENSO begins. This is known as **La Niña**, from the Spanish word for 'the girl child'.

ENSO events are measured using the ONI (**Oceanic Niño Index**). The ONI is obtained by measuring the sea surface temperatures in an area known as the Niño 3.4 region, which is a rectangular zone bounded by latitudes 5°N and 5°S, and longitudes 120°W to 170°W. The temperature readings are then used to calculate **mean anomalies** (deviations from normal) for three month periods of time. If there are five consecutive three month periods with warm temperatures at or above +0.5C°, then a warm ENSO, or El Niño, event is declared. If there are five consecutive three month periods with cool temperatures at or below -0.5C°, then a cool ENSO, or La Niña, event is declared.

Table 1.1 lists the El Niño and La Niña events since 1950 based on the ONI, as shown in figure 1.13. Both types of events are **natural occurrences**, and neither is predictable or regular. Figure 1.14 shows the world's ocean temperature anomalies at the peak of the very strong El Niño event of 2015-16.

1.15 Severe coastal bluff erosion, along the southern end of Ocean Beach, San Francisco, California (USA). The storm damage occurred during the 2009-10 El Niño event, which resulted in an average loss of 55 metres of Ocean Beach's shoreline.

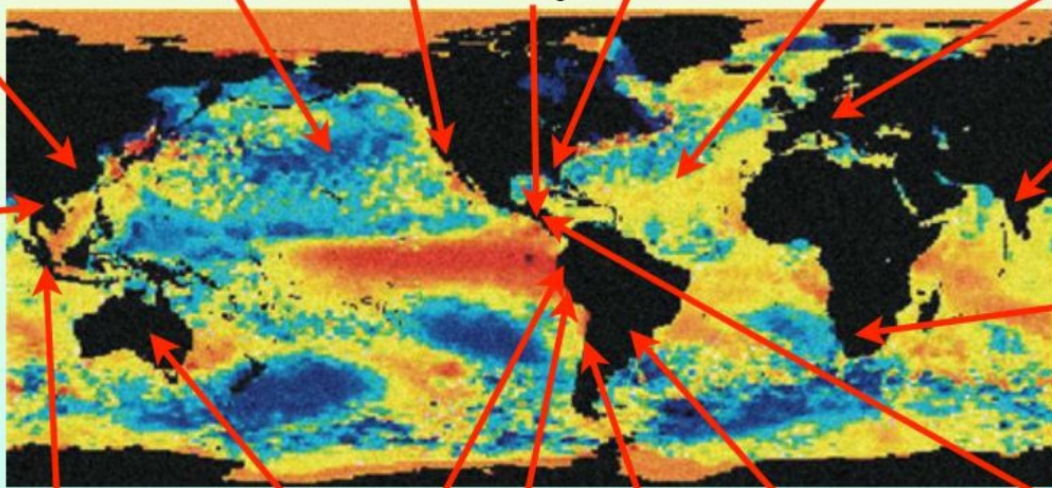


1.14 Sea surface temperatures in the Pacific Ocean on 1st March 2016, during a Very Strong El Niño event.Yellow, orange and red colours show areas where ocean temperatures are warmer than usual. The blue and purple colours show areas where the oceans are cooler than usual. The gradient below the map shows the deviation from normal temperature in degrees Fahrenheit. Source: NASA/JPL/PODAAC, NOAA.

**El Niño** events can have **drastic effects** on world climate impacting tens of millions of people. In the Atlantic Ocean and the Gulf of Mexico, tropical cyclone activity is suppressed, with the number and severity of cyclones being reduced significantly. On the other hand, **tropical cyclone** activity becomes more severe and plentiful in the Pacific Ocean. **Flooding** occurs in South America, whereas Australia, Indonesia and West Africa experience **drought** conditions. Several El Niño events have caused conditions in Indonesia to become so dry that huge **forest fires** have broken out, which have caused massive **smoke plumes** over much of South-East Asia. In the United States, El Niño usually means the north-western states facing the Pacific Ocean experience a warmer-than-normal winter, with less snow but with **more rain**. The heavy seas on the west coast of the United States lead to severe **coastal erosion**, with many homes being washed into the sea or undermined each time there is an El Niño event. The economic costs of damage and loss of production are very considerable, as seen in figure 1.16.

The **impacts** of **La Niña** are the opposite of El Niño. In general, La Niña aggravates **tropical cyclones** over the Atlantic Ocean and Gulf of Mexico and suppresses cyclone activity in areas of the Eastern Pacific. La Niña leads to **heavy rainfall** in Indonesia, South Asia and Australia, often with severe **flooding**, and stronger monsoon **rains** in south-east Asia. La Niña also increases the number and strength of **tornadoes** in the mid-states of the USA.

Although researchers now understand the impact of ENSO events, they are still unsure what **triggers** the movement of the warm ocean currents. In the past, it had been suggested that **volcanic eruptions**




**1.16** Impacts of El Niño events that have been recorded on multiple occasions.

may play a part, but this theory is no longer widely accepted because many El Niño events have not been preceded by eruptions. Other theories that have been suggested involve **sea floor venting** and **sunspots**, but no positive proof has yet been found to support these theories.

### Question Bank 1E

1. *Explain the meanings of the terms (a) El Niño, (b) La Niña, and (c) ENSO.*
2. *With reference to figure 1.10, explain how El Niño conditions vary from normal conditions.*
3. *Describe the pattern of sea surface temperature anomalies shown in figure 1.14. Explain why this pattern is typical of an El Niño event.*
4. *Explain how the pattern of sea surface temperature anomalies shown in figure 1.14 helps to explain the pattern of rainfall shown in figure 1.11.*
5. *Describe the impact of El Niño events in different parts of the world.*
6. *Describe the impact of La Niña events in different parts of the world.*

# Hurricanes and coastal margins

## Coastal hazards and storm surges

**Hurricanes**, which are also known as **typhoons** and **strong tropical cyclones**, are highly intense low pressure cells, with winds generally exceeding 120 kilometres per hour. They generate heavy rainfall and high waves in coastal areas, and represent a significant hazard to people living in tropical coastal areas.

Hurricanes form over warm, tropical ocean waters, and they spend most of their ‘lives’ over the warm oceans from which they draw their energy and moisture. For **hurricanes to form**, certain conditions are required:

- **Ocean temperatures** must be at least 27°C to a depth of at least 60 metres to provide sufficient energy to power the hurricane;
- The air above the ocean must be very **humid**;

- The low pressure cell that will develop into a hurricane must be far enough from the equator that the **Coriolis Force** (the force caused by the earth's rotation that deflects moving objects to the right in the northern hemisphere and to the left in the southern hemisphere) will cause the rising air mass to spiral;
- There should be very little **wind shear**, which means there is little difference in wind speed and direction over short distances; and
- Atmospheric conditions must be **unstable** so that condensation can occur to form clouds; this requires an air mass where the air temperature cools rapidly as the altitude gets higher.

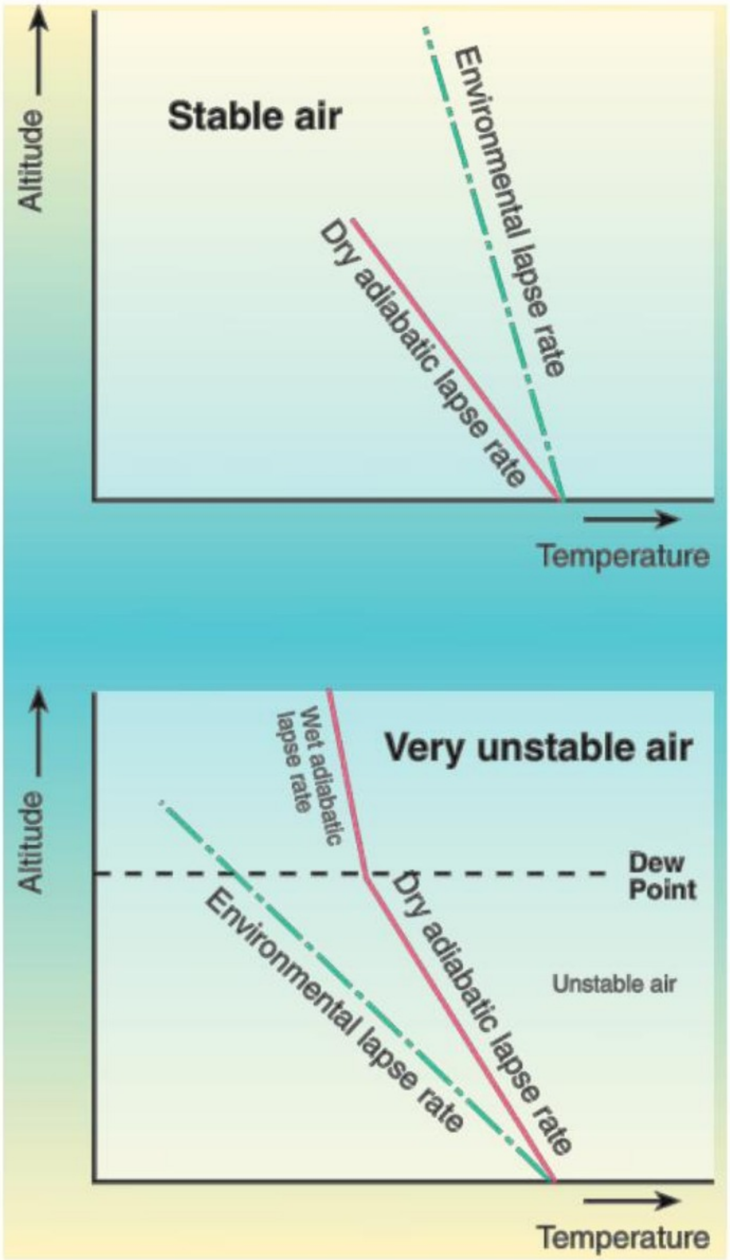
Air masses can be either stable or unstable. A **stable** air mass is one where a parcel of air cannot rise, and therefore where clouds and rain are unlikely to form. On the other hand, an **unstable** air mass is one in which a parcel of air can rise, and therefore where clouds and rainfall are likely.

To understand whether or not a parcel of air is likely to rise or not, we need to understand a little about **lapse rates**, which measure the relationship between temperature and altitude. If we plot the temperature of the air at different altitudes, we usually find that the **air becomes cooler with increasing altitude**. The rate at which the air becomes cooler is the **environmental lapse rate**. This can vary from place to place and from day to day, but an average value of about 6C° per 1,000 metres is common.

However, a body of rising air does not cool at the environmental lapse rate. Air rising from the earth's surface cools at a fixed rate of 10C° per 1,000 metres it rises, and this is known as the **dry adiabatic lapse rate**. Similarly, air which was descending would warm at 10C° per 1,000 metres. If a body of air rises far enough, it will cool down to the point where it becomes **saturated**. In other words, as the air cools, it condenses, and a point is reached at which the spaces between the molecules of air can no longer hold the water vapour that is in the air. The temperature at which this happens is called **dew point**.

Once dew point has been reached, the air cools at a slower rate as it rises. This slower rate is known as the **wet adiabatic lapse rate**, and it is a fixed rate of 5.5C° per 1,000 metres. Clouds that appear to have flat bottoms appear that way because the air above the flat bottom is saturated, but the air beneath is not. The flat bottom of such clouds indicates dew point at that place on that day.

An air mass is **stable** if a body of air **cannot rise**. This occurs when the environmental lapse rate is less than the dry adiabatic lapse rate. An air mass is **unstable** if the environmental lapse rate is greater than the dry adiabatic lapse rate, as this allows a **parcel of air to rise**. This is shown in figure 1.17.




1.17 Stable and unstable air

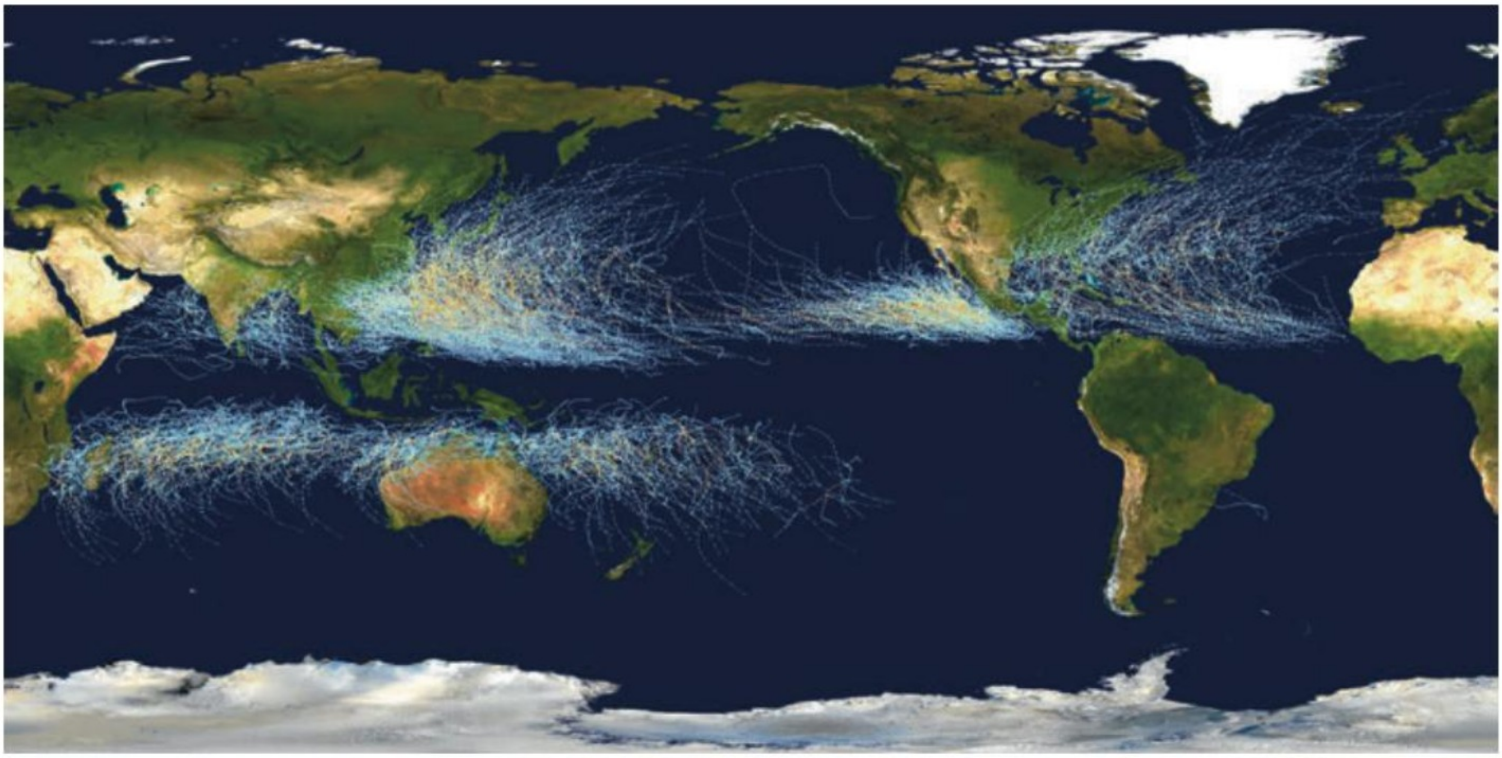
As a hurricane begins to form, unstable air rotates around the low pressure system, **anticlockwise** in the northern hemisphere and **clockwise** in the southern hemisphere. As the air spins, it rises, condenses vast quantities of moisture, and releases vast amounts of **latent energy**. This heats the air, forcing it to rise still further and more rapidly.

Further condensation accelerates the process, and before long an intense low pressure system develops with gale force winds spiralling around it. Hurricanes typically exhibit the following characteristics:

- The air is very **unstable**, and thus **rises** rapidly;
- Intensely **low air pressure** towards the centre, with a steep pressure gradient from the periphery into the centre; this is shown on weather maps by close, concentric isobars (lines joining points or equal air pressure);
- **Wind speeds** exceed 120 kilometres per hour, and may even exceed 250 kilometres per hour close the centre of the hurricane;
- A central calm area, known as the '**eye**', consists of a descending column of air with clear skies, calm conditions and warm air (perhaps 8C° to 15C° warmer than the air outside the hurricane);
- **Torrential rain** as warm moist air is carried up to great heights, resulting in condensation and precipitation;
- **Small diameter**, with most hurricanes having a diameter of less than 800 kilometres;
- **Spiralling bands** of clouds radiating into the 'eye'; and
- A path that usually takes a **westward** direction in both the northern and southern hemispheres, and then **away from the equator** towards the poles in a parabolic curve. As the hurricane moves away from the equator or over land, it loses its source of energy and weakens into a rain depression.

Figure 1.18 shows the **paths of hurricanes** for a period of 20 years. Hurricanes occur near the east coasts of all the continents except South America. The reason that hurricanes do not form off the eastern coast of South America is that the equatorial zone of air convergence rarely lies south of the equator over the Atlantic Ocean.

When hurricanes move into populated areas, they create a significant **hazard** as buildings are destroyed, and debris is blown about. The winds in hurricanes can tear roofs away from buildings, uproot trees, and damage power lines and communications. Additional hazards that can arise from hurricanes include coastal flooding and **storm surges**, which are rises in ocean levels produced by high winds and low atmospheric pressure. Besides causing flooding, storm surges can also increase coastal erosion, potentially causing slope failures. Hurricanes can even start fires by damaging power



1.18 The tracks of all hurricanes which formed worldwide from 1985 to 2005. The points show the locations of the storms at six-hourly intervals and use the colour scheme shown to the right from the Saffir-Simpson Hurricane Scale (see figure 1.19). Hurricanes form over warm oceans near the equator, and then move from east to west and away from the equator. Source: created with the WPTC track map generator by Nilfanion.

| Category | Wind speed (km/h) | Storm surge (metres) | Air Pressure (millibars) |
|---|---|---|---|
| Tropical depression | 0 - 62 | 0 | |
| Tropical storm | 63 - 119 | 0 - 0.9 | |
| Hurricane 1 - Weak | 120 - 153 | 1.0 - 1.5 | 980 or more |
| Hurricane 2 - Moderate | 154 - 177 | 1.6 - 2.4 | 965 - 979 |
| Hurricane 3 - Strong | 178 - 209 | 2.5 - 3.7 | 945 - 964 |
| Hurricane 4 - Very strong | 210 - 249 | 3.8 - 5.5 | 920 - 944 |
| Hurricane 5 - Devastating | 250+ | 5.6+ | Less than 920 |

**1.19** The Saffir-Simpson Hurricane Scale. The scale divides hurricanes into five categories according to the intensities of their sustained winds. In order to be classified as a hurricane, a tropical cyclone must have maximum sustained winds of at least 118 km/h (74 mph, 33 m/s; 64 knots). The highest classification in the scale, Category 5, is reserved for storms with winds exceeding 250 km/h (155 mph, 69 m/s; 136 knots). Officially, the Saffir-Simpson Hurricane Scale is used only to describe hurricanes that form in the Atlantic Ocean and northern Pacific Ocean east of the International Date Line. Other areas use different classification scales to label these storms, which are called 'cyclones' or 'typhoons', depending on the area.

**1.20** Hurricane damage in a suburban coastal area of Manila, the capital city of the Philippines.

lines. Contamination of drinking water and disruption of utility services, such as electricity, sewers and communications, are also common occurrences during hurricanes.

Coastal areas are especially **vulnerable** to storm surges caused by hurricanes. Many people are attracted to coasts as attractive and comfortable places to live. As a result of this, large numbers of people and their property are exposed to any hazard that arises.

The job of **coastal resource managers** is to assess the risk along the coast and make decisions about how people will cope during a possible future disastrous event. Sustainable development requires a dynamic balance of the human, social, economic and political systems within an area, allowing opportunities for growth while maintaining quality of life, water, and air, and at the same time protecting the natural and built environments. Although some coastal hazards cannot be prevented, hazard mitigation can improve the resilience of people and property.

**1.21** Cleaning up damage after a severe storm surge caused erosion of Collaroy Beach in Sydney, Australia. It undermined several homes, leading to their partial collapse.

**Hazard mitigation** is defined as sustained action that reduces or eliminates long-term risk to people and property from natural hazards and their effects. Hazard mitigation is important from an economic viewpoint to minimise property losses and large insurance claims. Of course, the cost in human lives can be even greater, and so it is important to protect the safety of the population and sustain the environment of coastal environments.

**Coastal changes** such as erosion of beaches, dunes and sea-cliffs, pose significant hazards to buildings and infrastructure that are built too close to vulnerable shorelines. The cost to society, in both money spent and lives lost, can be staggering.

Coastal planners must be able to **predict** where and how much coastal change will occur in order to locate new construction where it will be safe from coastal hazards. To be able to make accurate predictions, planners must take into account **factors** such as the climate of the area, the frequency of events such as hurricanes, the resilience of local landforms such as beaches, dunes and barriers, and the human land uses of the coastal zone.

A challenge for coastal planners is that the paths of hurricanes are quite **unpredictable**. Although we have a broad understanding that hurricanes move westwards and away from the equator, their precise pathways are notoriously difficult to predict. Hurricanes can **change course** suddenly, and therefore widespread coastal areas tend to prepare when a hurricane is in the vicinity with potential to make landfall. Coastal areas are especially vulnerable because hurricanes are often at their **maximum strength** when they make landfall, having gained energy from the warm ocean, but not yet having been weakened by passing over land.

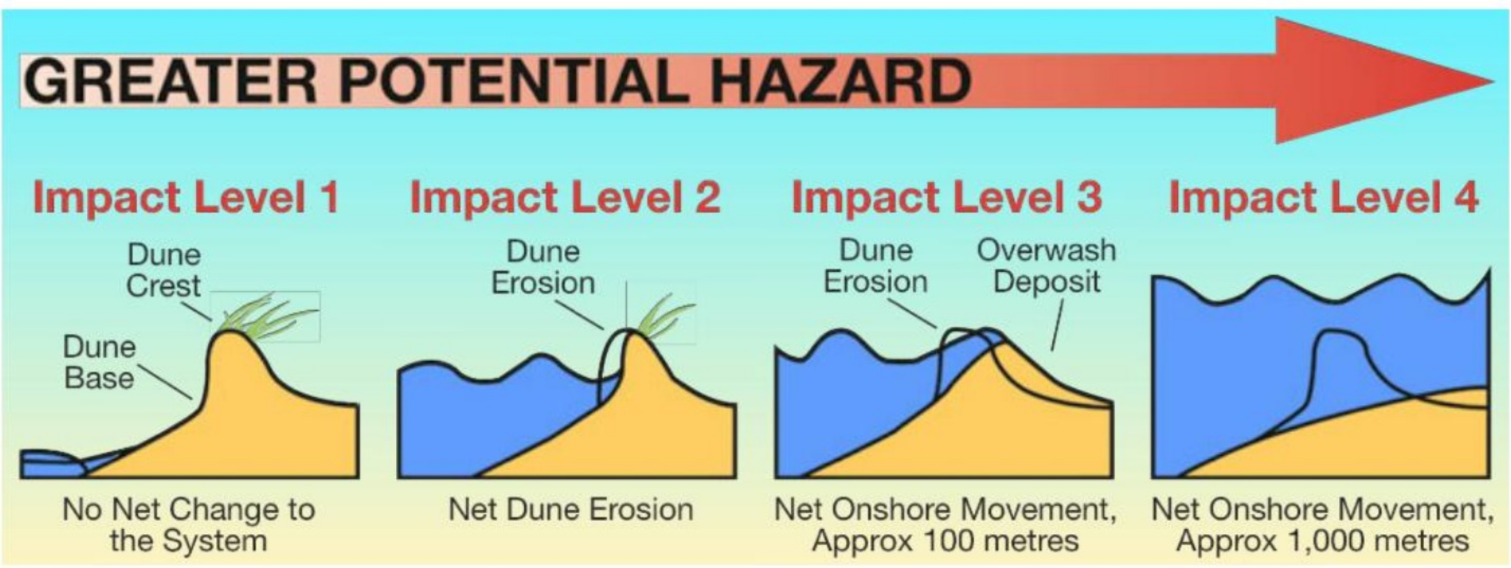
Another challenge is that the **strongest hurricanes** and storms are not necessarily the ones that will cause the most damage. The damage from a hurricane depends on the **angle** of the winds in relation to the shape of the coast, the size of the **population** in the area where the hurricane blows, and the strength of **buildings** and infrastructure in the affected area. In general, people in **poorer countries** are more vulnerable to damage caused by hurricanes because their housing is seldom built to withstand the full impact of strong winds and storm surges.

The impact of a storm on a beach or barrier island depends not only on the strength of the wind and the size of the storm surge and waves, but also on the **shape of the beach face**. This is especially important when the beach is in the form of a barrier island, as these are especially vulnerable to wave attack during storms. By considering the size (both height and length) of the approaching waves, and the highest reach of the waves on the beach, it is possible to classify the storm hazard according to four levels of impact, as shown in figure 1.22.

At **impact level** 1, waves affect the beach face through the alternating movement of swash and backwash. Overall, there is no (or minimal) net change to the beach. When storms occur, presuming wave action is confined to the beach face, the beach will usually erode and the sand will be stored offshore. However, during a period of several weeks to a few months after the storm, the sand will return naturally to the beach, restoring the beach to its original condition.

More severe erosion begins to occur if wave action exceeds the elevation of the base of the dune. In this situation, the swash will collide with the dune causing erosion and dune retreat. Unlike the temporary changes of impact level 1, this change is considered a net, or semi-permanent (and maybe even permanent) change to the dune, and is shown as **impact level 2** in figure 1.22.

If wave action is even higher and exceeds the elevation of the dune, or in the absence of a dune, the beach system will be covered by the incoming waves, transporting sand landward on a large scale. This is shown as **impact level 3** in figure 1.22, and leads to the migration of the barrier island landward, usually to a distance of about 100 metres.




1.22 The coastal change hazard scale.

If the storm surge is still higher and the elevation of the beach or barrier island is low, the barrier can become completely covered by the ocean water (**impact level 4** in figure 1.22). This is usually a major disaster, and sand is transported inland to distances of about one kilometre.

## CASE STUDY
## Hurricane Dennis and Hurricane Sandy in North Carolina

North Carolina is a state on the eastern coast of the USA. Situated south of Virginia and north of South Carolina, the length of the state's coastline is 484 kilometres. Because of the area's relatively warm climate and low costs, large numbers of families have been attracted to move into the coastal strip. Many of the **in-migrants** have built large houses, often right near the beach front.

1.23 Beach front residential development, Rodanthe, North Carolina, USA.

The region's beaches also attract large numbers of **tourists**. This can place particular pressure on the stability of the beaches and dunes as many of visitors prefer to drive all the way to the water's edge rather than walk over the dunes. Dunes are very **vulnerable** to disturbances such as car tyres, and this makes the dunes less resistant to wave action during times of storms. In an effort to protect the dunes, **elevated wooden pathways** have been built across the dunes in many parts of North Carolina, often connecting car parks in an effort to discourage driving onto the beaches.

North Carolina's coastline has a shape that protrudes into the Atlantic Ocean, and this makes it especially **vulnerable** to frequent hurricanes.

1.24 Driving across the sand dunes to park on the beach, Bodie island, North Carolina, USA.

1.25 Boardwalks have been built across the dunes of some beaches in North Carolina to reduce the erosive impact of trampling.

Frequent storm damage has led to a long-term trend of **coastal erosion** along the North Carolina coast, and on average, the North Carolina coast **recedes** about one metre per year with an average annual loss of about five square kilometres of land.

This strip of coastline has been experiencing high levels of erosion for many years, and yet is located in a fairly affluent country where funds are available to invest in well researched coastal management strategies. It is thus a particularly good example of how different approaches can be used to manage a stretch of coast.

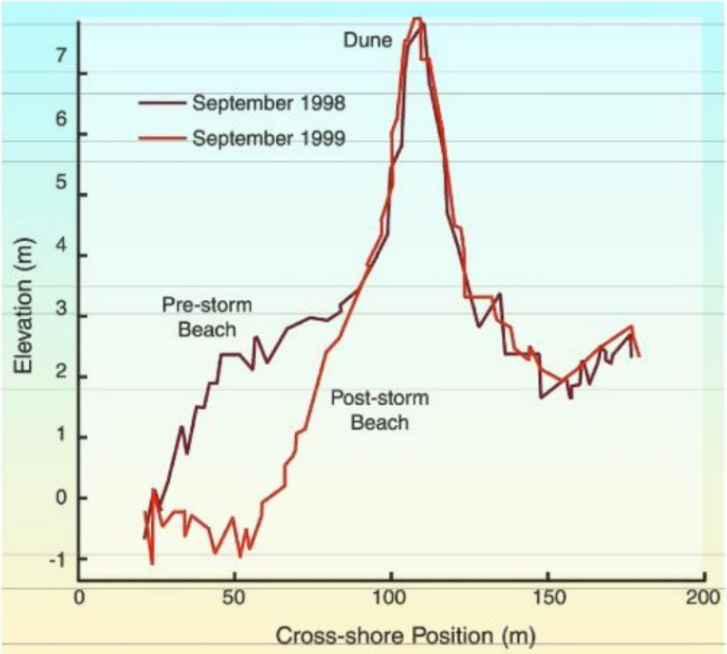
Each hurricane affects different sections of the coastline in various ways. For example, in the area shown in figure 1.26 at Bodie Island, a sandy barrier on the North Carolina coastline, wave action from a hurricane shortly before the photo was taken was confined to the beach, even during the storm.

As a consequence, the beach was eroded but the dune remained untouched. Most of the eroded sand returned to the beach over the following weeks and months, although when the photo in figure 1.26 was taken, evidence of beach erosion could still be seen.

1.26 Bodie Island, North Carolina, USA.

Figure 1.27 shows the 'before' and 'after' profile of the same beach as a result of one tropical cyclone, **Hurricane Dennis** in 1999. This diagram shows that the severe impact was confined to the beach, leaving the dunes untouched. In this case, the effects of the storm were restricted to impact level 1 in figure 1.22.

More severe erosion from the same storm occurred a little further south on Bodie Island where the angle of the coastline made it more exposed to the




1.27 The cross-section profile of the beach shown in figure 1.26, showing the impact of Hurricane Dennis in 1999. The seaward edge of the beach is at the left of the profile.

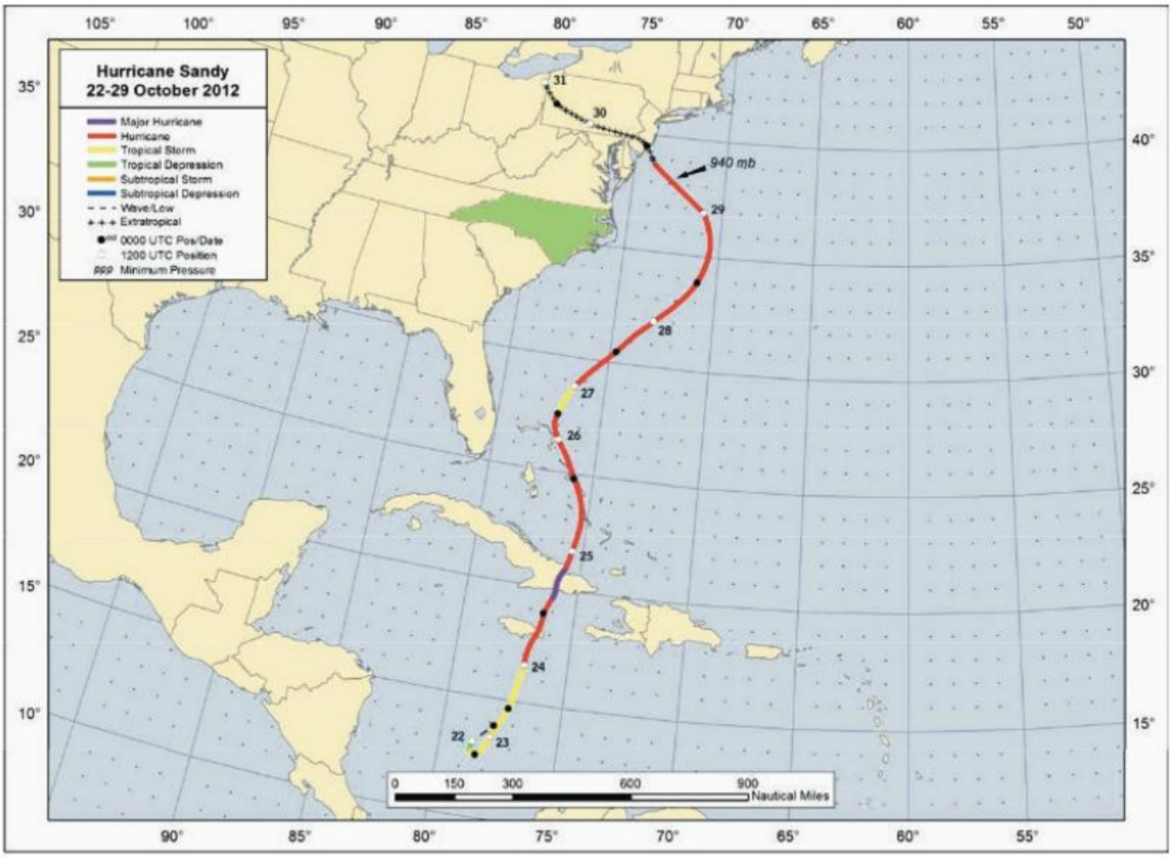
waves generated by the hurricane. At Bodie Island, the swash reached the dune zone and removed most of the dune sand. This was an example of **impact level 2** erosion, and can be seen in figure 1.28.

1.28 Level 2 erosion at Bodie Island, North Carolina, USA.

**Impact level 3** erosion occurred at Cape Hatteras, a very exposed sandy headland south of Bodie Island. At Cape Hatteras, the incoming waves were so high in energy that they completely destroyed the dune zone, flattening and moving the sand landward by about 100 metres (figure 1.29).

1.29 Level 3 erosion at Cape Hatteras, North Carolina, USA.

Hurricane Dennis was not the strongest hurricane to affect North Carolina in recent years. On the Saffir-Simpson scale, Hurricane Dennis was a force 2 hurricane. In late October 2012, **Hurricane Sandy** (a force 3 hurricane) hit North Carolina together with much of the US east coast as far north as New York. Hurricane Sandy brought winds of 185 kilometres per hour to North Carolina, and atmospheric pressures as low as 940 millibars.




1.30 The track of Hurricane Sandy from the Caribbean (22nd October 2012) north to its landfall near New York on 29th October 2012. North Carolina is shaded light green. Source: National Hurricane Center (NHC) Sandy Report

The main impact on North Carolina's coastline was to the beachfront **wave-sediment zone**, and the dune areas behind the beaches. As a result of the storm surges during the hurricane, dune erosion resulted in lowered elevations of two to four metres on some of North Carolina's beaches. In the section of coastline between Cape Hatteras and Oregon Inlet, 14% of the dunes lost two metres or more in dune height erosion.

As Hurricane Sandy moved northwards past North Carolina, it brought gale force winds to the coastline. Hurricane Sandy was the second costliest hurricane in US history, but the damage in North Carolina was mainly confined to the coastal zone where severe erosion affected the already vulnerable coastline.

In Rodanthe, storm surge and wave erosion moved vast quantities of sand, eroding some sand offshore and shifting other sand landward behind the dune zone. As a result of this movement, the **shoreline shifted** landward by about 10 metres, making many houses built on the beaches more vulnerable to future erosion and undercutting.



1.31 (left) and 1.32 (right) Oblique aerial photographs of Rodanthe, North Carolina, looking west towards the North Carolina shoreline. Figure 1.31 shows the shoreline before Hurricane Sandy, whereas figure 1.32 shows the post-hurricane shoreline. Beach erosion during Hurricane Sandy has shifted the shoreline landward so that the ocean waters reach houses built on the beach. Sand on the roads behind the beach shows landward transport of sand by overwash. This is impact level 3 erosion, using the scale in figure 1.22. The yellow arrow in each image points to the same feature.



**1.33 (left) and 1.34 (right)** Oblique aerial photographs of Pea Island National Wildlife Refuge, Kinnakeet, North Carolina, looking west towards the North Carolina shoreline. Figure 1.33 shows the shoreline before Hurricane Sandy, whereas figure 1.34 shows the post-hurricane shoreline. Extensive overwash can be seen in the post-hurricane photo. The road, which had been buried during the storm, is being uncovered by heavy machinery. This is impact level 3 erosion, using the scale in figure 1.22. The yellow arrow in each image points to the same feature.



**1.35 (left) and 1.36 (right)** Oblique aerial photographs of Pea Island National Wildlife Refuge, Kinnakeet, North Carolina, looking west towards the North Carolina shoreline. Figure 1.35 shows the shoreline before Hurricane Sandy, whereas figure 1.36 shows the post-hurricane shoreline. Overwash has transported sand across the island (and the road), and an overwash fan has been deposited on the marsh and in the estuary, indicating impact level 4 erosion, using the scale in figure 1.22. The yellow arrow in each image points to the same feature.

In other areas where the beach face comprised a thin sandy barrier, the storm surge and waves produced **overwash**, depositing sand over coastal roads and into the lagoon areas on the landward side of the beach barriers. This indicated impact 3 and impact 4 erosion, as shown in figure 1.22.

As a result of **long-term coastal erosion** in North Carolina, especially as a result of storm surges during hurricanes, there has been large-scale loss of buildings along the coastline. Houses in the coastal areas are especially vulnerable to coastal erosion because loose building regulations have allowed many of them to be built very close to the ocean, in some cases on the dunes and even on the seaward side of the dunes. There have been many examples of houses that were destroyed by waves and then

**1.37** Many houses have been built dangerously close to the surf zone at Rodanthe, North Carolina, USA. These houses are especially vulnerable to undercutting by storm surge waves.

1.38 Fences have been built on this beach at Rodanthe, North Carolina, to reduce erosion of the dunes by wind, and to a lesser extent, by longshore drift action by waves. The fences break up winds that blow along the beach, reducing their speed and capacity to transport sand.

re-built in the same locations.

**In response** to the threat of erosion, **coastal management strategies** can help to protect people and property against more common coastal erosion. Most management strategies have attempted either to **divert** wind or wave **energy** away from the beach, or else to **absorb** the energy when it arrives at the beach. Devices used to achieve these goals may be placed on the beach itself, or in the water near the beach.

Two types of device that have been placed in the water near beaches are breakwaters and artificial seaweed. **Breakwaters** are structures that are built offshore parallel to the shoreline, either submerged or floating. They dissipate wave energy by forcing waves to break before they reach the shoreline, creating a 'wave shadow' causing a loss of wave energy and deposition of sand. However, problems have arisen when breakwaters have been built. Wave action may cause scouring (erosion) near the breakwater, they may cause downdrift erosion by removing sediment from incoming waves, they can reduce water quality by impeding natural patterns of circulation, and they may endanger swimmers or boaters.

**Artificial seaweed** consists of low-lying devices made from materials such as plastic, wire, concrete or old tyres, that are anchored to the sea floor. They are designed to slow down incoming waves and reduce energy, causing the waves to drop any sand that they are carrying. They are also designed to slow down the waves returning to the sea from the beach, causing sand that is being removed from the beach to be deposited close to the shoreline. Problems with these devices have been that they can be hazardous to swimmers and boaters when they are placed in shallow water. Furthermore, many examples lack the mass or design to remain anchored to the sea floor during storms and therefore they can create debris on beaches when washed up during storms.

Perhaps because they are easier and usually cheaper to install, devices placed on the beach are more commonly used than devices that are placed in the water. One common device is the **groyne**. Groynes are walls or fences that are built at right-angles to the shoreline, extending from the beach into the water, and they are designed to trap sediment that is moving along the shoreline (longshore drift). Groynes have been installed at several points on the North Carolina coastline, including the exposed beaches near Cape Hatteras. Although they are generally successful in slowing or stopping longshore drift, they can cause erosion of downdrift beaches as they become starved of sediment. Groynes may create hazardous rip currents, and they are a nuisance to recreational beach use.

1.39 A groyne at Cape Hatteras, North Carolina, USA.

An 'engineering' response to the problem of coastal erosion that has been used in North Carolina is **dewatering**. In the process of dewatering, a drain and pump system extracts water from the saturated zone beneath the sand, allowing more percolation of incoming waves. When water percolates through the sand, the sand being carried by the incoming wave is deposited on the surface, causing the beach to receive additional supplies of sand that would normally have simply returned to the sea with the backwash. The water that is pumped out from under the beach is either piped out to the ocean or, if it is fresh water, collected as a resource. Three main problems have been identified with dewatering. First, dewatering must be turned off during the nesting season of animals such as turtles because it affects the temperature of the sand. Second, the system does not seem to withstand the additional pressure of waves during storm times. Finally, swimming must be banned in front of the extraction pipes because of the possible hazard.


**1.40** Efforts are made to protect breeding grounds on some beaches in North Carolina.

One response to the erosion of natural dunes in North Carolina has been to replace them with **artificial dunes**. This is a form of beach nourishment where sand is brought from elsewhere, usually a place where the beach has less economic value as an attraction to tourists, and dumped on the beach that has lost sand due to erosion. Often, the artificial dunes have an unnatural appearance, but they nonetheless provide protection for beach dwellings, until the next storm anyway.

**Dune stabilisation** is a technique used in many parts of the world, and it has become important in North Carolina. This is achieved in various ways, such as placing low lying barriers on the beach to prevent erosion, planting grass to trap wind and thus stabilise the dune, or covering the dune with some protective layer such as cut-down tree branches, spray-gel, rock-filled mattresses, old tyres or polymer yarn. Shortcomings of these devices are few, although it should be noted that walls and

**1.41** Artificial dunes, North Carolina, USA.

**1.42** Artificial dunes have been built in an effort to protect houses on this heavily eroded beach in North Carolina, USA.

fences only protect the land on the leeward side of the structure and offer no protection to the area of the beach in front of it. Furthermore, dune stabilisation may lead to passive erosion in that sand is trapped by the device, and the beach is therefore unable to respond to a rising sea level by retreating.

Following the loss of several homes to storm damage in the late 1990s and early 2000s, the North Carolina Department of the Environment and Natural Resources established **stricter guidelines** for the location of new buildings. The Department's Division of Coastal Management has produced maps showing the rate of coastal retreat for each local area. Based on this information, residents are now required to construct new buildings at certain distances back from the sea, the precise distance depending on local circumstances. The Division defines an erosion setback line, which

**1.43** This low sand dune has been re-vegetated with local grasses in an effort to stabilise it and reduce its vulnerability to wave attack during storm surges.

is the closest distance that a house can be built to the shoreline. The erosion setback line is measured inland starting at the first line of stable, natural vegetation. The minimum erosion setback line is now set at 18 metres, and within that limit is calculated by multiplying the average annual erosion rate (in metres per year) by 30. Therefore, in areas which are experiencing the average rate of coastal retreat (one metre per year), then any new building would need to be at least 30 metres inland from the first line of stable, natural vegetation found on the dunes nearby.

### Question Bank 1F

1. *What the requirements for a hurricane to form?*
2. *What do we mean when we classify an air mass as 'stable' or 'unstable'?*
3. *What are the typical characteristics of hurricanes?*
4. *What is a storm surge, and what damage can they cause?*
5. *Describe the pressures placed upon North Carolina's beaches by (a) residents, and (b) tourists.*
6. *Why is North Carolina vulnerable to hurricanes?*
7. *Describe the impact of (a) Hurricane Dennis and (b) Hurricane Sandy on North Carolina's coastline.*
8. *Give an example of erosion caused by a hurricane in North Carolina at each level of impact: 1, 2, 3 and 4.*
9. *Rank the management strategies that have been used on North Carolina's beaches in descending order of effectiveness (in your opinion). Then explain why you ranked the management strategies in the order that you did.*

# Oceans as a store of carbon dioxide

## Carbon dioxide in the oceans and the carbon cycle

Earlier in this chapter, we saw that the THC (thermohaline circulation) is a source of adding carbon dioxide into the atmosphere. The relationship between the world's oceans and the atmosphere is important and complex, and to understand this relationship, it is useful to see it in the broader context of the carbon cycle.

The **movement of carbon** across the planet is vital, as all life is composed of carbon compounds of one kind or another. Carbon dioxide is a very minor part of the atmosphere, but this small reservoir is being continually recycled through living things on the earth's surface.

Table 1.2

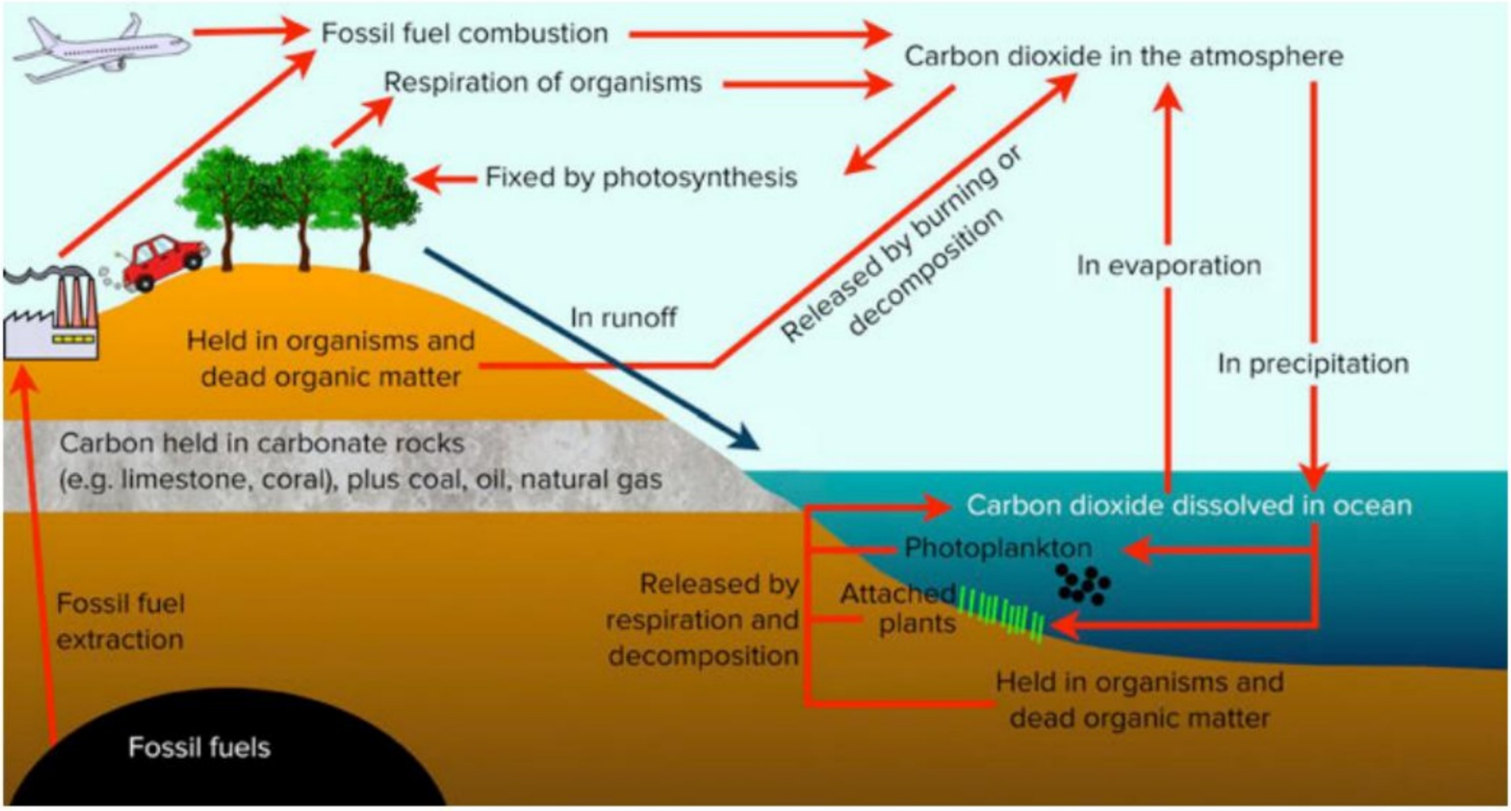
The Earth's stores of carbon

| | Location | Billions of tonnes |
|---|---|---|
| ACTIVE | Carbon dioxide in the atmosphere | 700 |
| ACTIVE | Held in organisms and dead organic matter on land | 3,000 |
| ACTIVE | Dissolved in oceans | 37,000 |
| ACTIVE | Held in organisms and dead organic matter in oceans | 2,000 |
| | Held in carbonate rocks | 20,000,000 |
| | Held in fossil fuel reserves | 12,500 |

Source: Chapman and Codrington (1985), p.236

As table 1.2 shows, a large amount of carbon dioxide is dissolved in the water of the oceans. The amount of carbon stored in fossil fuels is considered to be relatively small compared with the amounts contained in the atmosphere and the oceans. Carbon that is classified as 'active' is available for exchange between the atmosphere, the oceans, the earth and living things through the **carbon cycle** (figure 1.44).

The carbon cycle consists of a network of stores and flows. Major **stores** within the carbon cycle include carbonate rocks, fossil fuel reserves, the oceans,




**1.44** The carbon cycle.

atmosphere, and living organisms and dead organic matter.

Movement (or **flows**) within the carbon cycle begin with the primary production of carbon by living organisms through photosynthesis. Carbon dioxide is turned into organic carbon compounds, which are ultimately converted back into carbon dioxide by respiration and by the activities of soil bacteria. In addition to this source of carbon, fossil fuel deposits yield carbon through mining and combustion at a rate about equal to one-fifth of the net fixation by land plants.

Since widespread industrialisation began about 200 years ago, the increasingly rapid conversion of carbon from a storage to an active form has produced a **significant increase** in the amount of carbon dioxide in the atmosphere.

The ocean serves as a **carbon sink** because overall it absorbs more carbon from the atmosphere than flows back from the ocean to the atmosphere. In other words, there is a net movement of carbon from the atmosphere to the oceans. This occurs as atmospheric carbon dioxide dissolves in the surface waters of the ocean, especially when the ocean surface is churned up by the wind. Carbon dioxide also flows from the atmosphere to enter the oceans through precipitation.

When carbon enters the ocean waters, some of it is retained as dissolved gas, but most of it is used by marine organisms such as **photoplankton** in the process of photosynthesis. Photoplankton are known as **autotrophs**, which means they can convert light energy or chemical energy into organic matter. Photoplankton are consumed by marine organisms (**heterotrophs**), which are in turn consumed by larger marine organisms in a food chain. At each higher level in the food chain, the concentration of carbon increases.

Photoplankton build skeletal structures composed of calcium carbonate. When photoplankton die, the mineral matter of their skeletons settles down on the ocean floor to build up layers of calcium carbonate as sedimentary strata. Photoplankton also provide food for coral polyps (one example of a marine heterotroph), which in turn secrete skeletons of calcium carbonate to form **coral reef**s.

Living organisms that absorb carbon are an important mechanism for moving carbon around within the oceans. Organisms move carbon from the ocean surface to deeper water, and when the organisms die, the carbon moves again to the ocean floor. The downward movement of carbon in marine organisms is known as a **biological pump**. When the dead organisms decay, carbon dioxide is released into the deep ocean waters.

As shown in table 1.2, the oceans hold over 50 times more carbon than the atmosphere. Oceans can hold much more carbon dioxide than the atmosphere because most of the carbon dioxide that transfers into the oceans reacts with the water to form carbonic acid, bicarbonate and carbonate ions . This process reduces the **gas pressure** of carbon dioxide in the water, thus permitting more and more absorption from the atmosphere.

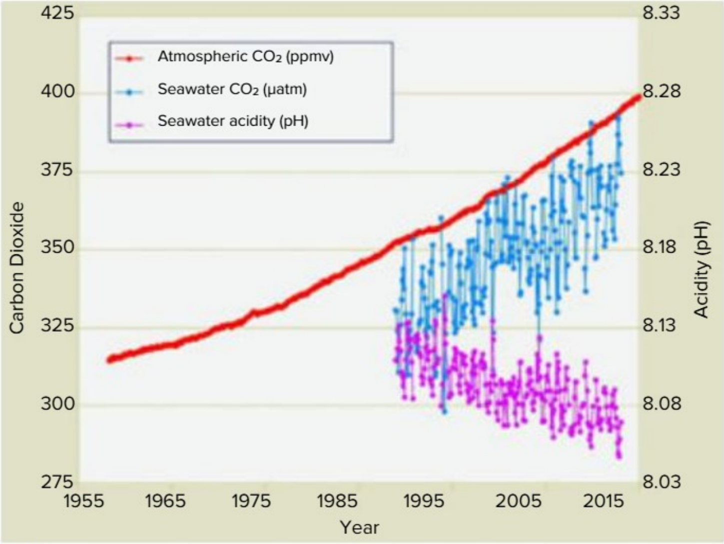
Mixing of water in the oceans occurs at a much slower rate than the mixing of gases in the atmosphere. Consequently, there are large differences in the **concentration** of carbon dioxide within the oceans, both horizontally and vertically. In general, tropical waters **release** more carbon dioxide to the atmosphere than they absorb, whereas oceans near the poles **absorb** more carbon dioxide than they release. Furthermore, the concentration of carbon dioxide is about 10% higher in the depths of the oceans than at the surface.

**Human activity** is affecting the carbon cycle to a growing degree. Burning fossil fuels releases vast quantities of carbon dioxide into the atmosphere at a rate that is far beyond the rate of any natural processes, bringing carbon into the 'active' part of the carbon cycle that would normally be stored in rocks and soil. About half the carbon that is released by fossil fuel burning remains in the atmosphere, while oceans absorb most of the other half. In addition, a much smaller volume of the carbon produced during fossil fuel burning is absorbed by plants, whose growth is stimulated by the additional carbon. By this process, plants become a sink for carbon dioxide that becomes available for release into the atmosphere when the plant dies and decays, or is burnt.

Despite the ocean's role in absorbing the additional carbon dioxide released by burning fossil fuels and deforestation, the concentration of carbon dioxide in the atmosphere continues to rise. Carbon dioxide is a **greenhouse gas**, which means it prevents heat escaping from the atmosphere into space. Therefore, an increasing amount of carbon dioxide in the atmosphere means more heat is trapped, which results in rising temperatures. It is generally accepted that this increase is a major contributor to **global warming** of the earth.

The carbon that is absorbed from the atmosphere into the oceans **offsets** human-generated global warming because carbon dioxide in water no longer traps heat. The oceans therefore **mask** some of the impact of global warming. Carbon dioxide that is absorbed by the oceans no longer affects the planet's heat balance, so understanding the exchange of carbon dioxide between the atmosphere and the oceans is an important part of understanding our climate system and the potential impact of future carbon dioxide emissions.

However, there is a downside to the ocean's absorption of additional human-generated carbon dioxide. As shown in figure 1.45, as the proportion of carbon dioxide in the ocean increases, chemical reactions cause the ocean's acidity to increase. Known as **OA**, or **ocean acidification**, the pH (which measures acidity) of the world's surface ocean waters has fallen by 0.1 over the past 200 years. The pH scale is logarithmic, and so a fall of 0.1 represents a 30% increase in surface water acidity. Measurements show that the world's oceans have not been so acidic for more than 20 million years.

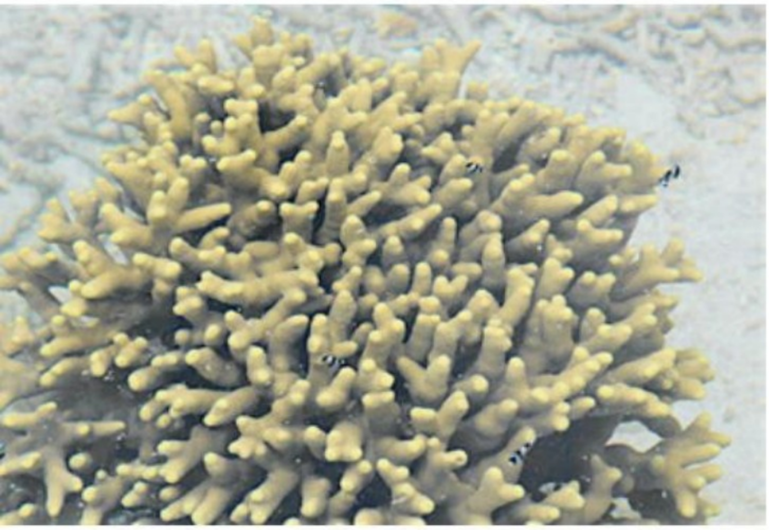



**1.45** The relationship between rising levels of carbon dioxide ($CO_2$) in the atmosphere at Mauna Loa (Hawaii, USA) with rising levels of $CO_2$ and acidity in the nearby ocean. As $CO_2$ accumulates in the ocean, the pH of the ocean decreases, indicating that the ocean water is becoming more acidic. Source: modified after Feely (2008)

Although increased levels of carbon dioxide in the oceans benefits some species, such as algae and sea grasses, increasing acidity has a **devastating impact** on species that have skeletons of calcium carbonate, such as oysters, clams, corals and some plankton, because calcium carbonate dissolves in acid.

## Impact of ocean acidification on coral reefs

Because of their **slow rates of growth**, coral reefs are vulnerable to damage and destruction. It is estimated that 58% of the world's coral reefs are potentially threatened by human activity, and according to Seaweb (an online organisation that advocates better conservation of ocean environments), coral reefs are threatened in 93 of the 109 countries where they are found. The world has already lost 27% of its coral reefs, and if present rates of destruction continue, 60% of the world's coral reefs will be destroyed over the next 30 years.



**1.46** Healthy coral on a reef in Fiji. Compare this with the bleached coral shown in figure 1.47.

**1.47** A bleached coral reef affected by Montipora White Syndrome. Note the large swath of white skeleton tissue surrounded by normal (brown) corals.

One of the main threats to coral reefs comes from **coral bleaching**, which is the whitening of the coral polyp due to a reduction of photosynthetic pigment. Bleaching occurs due to a change in the relationship between the coral polyp and microscopic algae known as **zooxanthellae**. Coral and zooxanthellae live in a **symbiotic relationship**, which means that each depends on the other for survival. The coral receives about 90% of its energy requirements from the zooxanthellae.

Bleaching occurs when the coral expels its zooxanthellae. As most of the colour of coral comes from the photosynthetic pigments of the zooxanthellae, the tissue of the coral animal becomes transparent when the zooxanthellae are expelled and the bright white skeleton of the coral is revealed, giving the reef a sickly white colour.

Bleaching is a sign of **stress**, and it can be caused by a variety of factors including changes in the ocean **temperature**, changes in the water chemistry (especially **acidification**), increasing **sedimentation** (especially from soil erosion), and **dilution** of the saline content by freshwater.

**Acidification**, the decrease in the pH of the Earth's oceans, is a consequence of global climatic change. Acidification occurs when the ocean surface absorbs carbon dioxide from the atmosphere. Measurements suggest that the current rate of pH decline is 100 times faster than the natural rate of decline.

When **ice sheets** in the Arctic and Antarctic collapse as a result of global warming, minerals and nutrients from eroded soil and bedrock are released into the sea that encourage the growth of photosynthetic plankton, which boost the absorption of carbon dioxide from the atmosphere. It is estimated that each year, Antarctic icebergs deposit 120,000 tonnes of iron into the Southern Ocean which promotes enough growth in plankton to sequester (absorb) 2.6 billion tonnes of carbon dioxide — the equivalent combined annual emissions of India and Japan. Although this has a positive effect in reducing the build-up of atmospheric carbon dioxide, it makes the problem of acidification of the oceans worse, and scientists warn that it may make most of the world's oceans inhospitable to coral reefs by 2050.

Once bleaching occurs, corals begin to starve. If conditions return to normal quickly, then the corals can regain their zooxanthellae, return to normal colour and survive. However, the stress of even short-term bleaching usually leads to decreased growth of coral and reduced reproduction as well as less resistance to disease. If the cause of the bleaching lasts more than ten weeks, it usually leads to the **death** of the coral.

Some of the causes of coral bleaching are natural. For example, strong winds, exposure at low tide and certain weather conditions can all cause bleaching. Annual bleaching of coral each summer is also a normal occurrence as increases in solar radiation affect the reef.

1.48 A healthy coral reef surrounds the western edge of Upolu Island in Samoa.

Another threat to coral reefs (that also causes bleaching) is destructive **fishing practices**, such the use of poisons. Some large-scale fishing operations deliberately try to reduce coral cover to make fishing easier. They may also remove fish that are important elements in the food chain of the reef. In places where overfishing occurs, the food chain is disrupted and there is a decline in zooplankton, which in turn starves the coral.

Once bleaching begins, corals usually continue to bleach even if the stressor is removed. If the coral in a community survives the bleaching, it often takes weeks or months for the food web to re-establish itself, and it is fairly common for a bleaching to result in the **colonisation** of the reef by new species.

Many researchers argue that the greatest threat to coral reefs is **global warming** because corals are so vulnerable to small changes in ocean temperature. Temperature increases of only 1.5C° to 2C° for six to eight weeks are usually sufficient to trigger coral

1.49 Dead coral on a beach in Hong Kong.

bleaching. If those temperatures continue for more than eight weeks, the coral will almost certainly not survive. According to the IPCC (Intergovernmental Panel on Climate Change) 2007 assessment, coral reefs will be highly vulnerable to increased and more frequent bleaching events as a result of global warming, and this negative impact will be magnified by the additional problem of increasing acidity resulting from increased carbon dioxide during the period to 2040.

According to some estimates, about half of the world's coral reefs will die within the next forty years from human causes unless significant measures are taken to save them from the impact of global warming. Mass bleaching has now been seen to affect every reef region in the world, and both the frequency and severity of bleaching events seem to be increasing.

## Question Bank 1G

1. *With reference to table 1.2, what percentage of the world's active carbon is in the oceans?*
2. *Briefly describe the carbon cycle, making specific references to components that are (a) stores and (b) flows.*
3. *How is carbon transferred between the atmosphere and the oceans? In which direction is the larger net movement?*
4. *How are human actions affecting (a) oceanic carbon dioxide levels, and (b) oceanic acidity?*
5. *What is the impact of increasing ocean acidity on coral reefs?*
6. *Describe the causes of coral bleaching, and explain why it is a problem.*

# Chapter 2 Interactions between oceans and coastal places

2.1 Wave action has an important influence on the development of coastal landforms, both depositional and erosional. In this view, waves refract around a rock platform at the northern end of Currumbin Beach, Australia.

## Physical influences on coastal landscapes

### The shoreline environment

The coast is a narrow zone that is especially active in the shaping of landforms. In the **coastal zone** the sea, land and air all meet together and interact to shape the landforms, which are in turn heavily influenced by human activity. The **shoreline** is the actual boundary of the land and sea. However, when we study the **coastal margins**, we usually look a little more widely than the shoreline.

**Coastal terrains** extend inland as far as the sea water, salt spray or wind-blown sand extends. They extend seawards to the depth of the **wave base**, which means the depth to which waves can move sediment on the sea bed.

It follows from this that the width of a coastal terrain in one area may be very different from its width somewhere else. The coastal terrain may be only a few tens of metres wide on steep, rocky coasts, but it could be tens or hundreds of kilometres wide where estuaries move sea water far inland or where there are wide shallow continental shelves. On the high energy coastlines of southern

Australia, the wave base may be 20 metres below sea level, but on the low energy coastlines common in western Europe, the wave base may be only a few metres below sea level.

2.2 The steep beach face, rocky outcrops and powerful waves indicate that this coastline at Khalaktriskiy in the Russian Far East is a high energy shoreline.

2.3 The wide expanse of sand and low waves indicate that this coastline at Banjul, Gambia, is a low energy shoreline.

With the exception of some glacial processes, all the **processes** that form landforms anywhere in the world can be found operating on coastal terrains. In addition, there are many unique processes that operate in coastal terrains. On any coastline, there are **inputs** of water, sediment and energy. When the level of any of these three variables changes, such as during a storm, **changes** to the landforms will result. The **physical processes** acting on coasts are mostly marine or atmospheric, although other important processes include the work of chemical and biological factors.

## Marine processes

**Marine processes** are the action of waves, tides and currents – these supply most of the **energy** that shapes landforms in the coastal zone. The original sources of energy that drive marine processes are solar radiation and the gravitational pull of the sun and moon.

The small undulations of the water surface produced by the wind blowing over the open ocean are called **wind waves**. Small circular movements in the wind produce minor undulations in the water surface, and some of these are reinforced by subsequent gusts of wind. The stronger the wind, the larger the waves will be. Although wind waves are highly visible to someone standing on the shoreline, they are not the waves that perform most of the work of landform formation.

**Larger waves** are formed by a wind that blows for a long time or which has a long **fetch** (the distance over which the wind blows). When these larger wind waves leave the area where they were formed and begin to travel freely, they become more evenly spaced with longer crests, and they become known as **swell**. These waves have considerable potential to shape landforms on the shoreline.

It is possible to **measure** waves, and this helps us to distinguish between **constructive** or **destructive** waves. Many of the measurements focus on the crests, or tops of the waves, and the troughs, or dips between them. Some of the important measures commonly used are the following:

**Wave height (H)** is the vertical distance between a crest and its adjoining trough.

**Wave length (L)** is the horizontal distance between two successive crests.

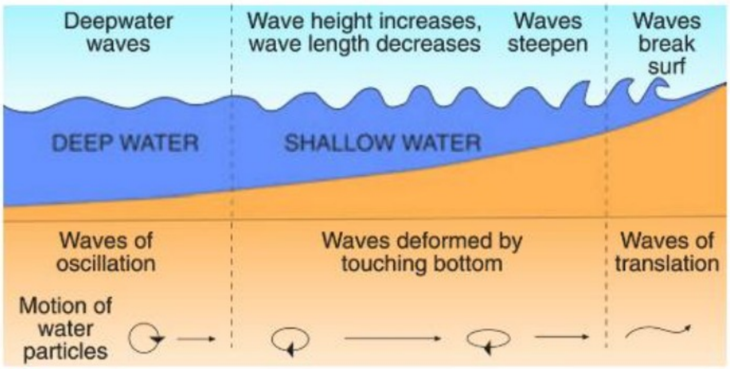
**Wave period (T)** is the time taken for two successive crests to pass a fixed point.

**Wave velocity (V)** is the speed of the wave crests.

**Wave steepness (H/L)** is the ratio of wave height to wave length.

Wave steepness cannot exceed a ratio of 1:7, or 0.14, because at that point the wave breaks. It is possible to calculate the wave length if the wave period is known. This can be done using the formula $L = 1.56T^2$.

**2.4** Waves approaching the shoreline become deformed with increasing wave height and decreasing wave length. As the waves steepen, they come into contact with the underlying sediment base, which causes them to become waves of translation, or 'breakers'. This view shows Tamarindo Beach, Costa Rica.




**2.5** Changes in the shape of a wave as it approaches the shoreline.

exerts. Larger waves possess more energy, and therefore have a greater potential to cause damage. Wave energy (E) is proportional to the square of the wave height (H), and directly proportional to the wave period (T), using the formula E ∝ LH2. In other words, a 4 metre high wave has 16 times more energy than a 1 metre wave, assuming the same wave length. Similarly, a wave with an 8 second period has 4 times more energy than one of the same height with a period of 2 seconds, assuming the same wave height. This shows us that long period, high waves can do as much work in a few days as it takes smaller waves several weeks or months to do.

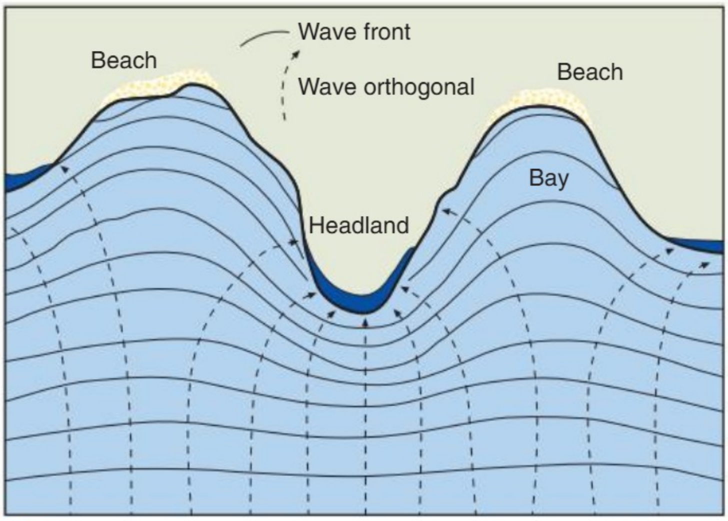
**Wind velocities**, and therefore **wave heights**, are greatest in the mid-latitudes where strong winds blow for long periods across large stretches of ocean. Wave velocities and wave heights decrease towards both the equator and the poles. Because the prevailing winds over the oceans blow from the west, more moderate waves tend to be found along the east coasts of continents in the mid and low-latitudes, as these coasts are protected from the west coast swell. In the tropics, where very gentle winds blow or calms prevail, low waves are most common.

**2.6** The difference between west coast and east coast shorelines can be seen by comparing two very different coasts that are found near each other in Auckland, New Zealand. The land mass of the North Island is very narrow in this area, and New Zealand's east and west coasts are separated by just a few kilometres. This photo shows the high energy coastline of Muriwai, which faces the Tasman Sea to the west. Compare this to the coastline in figure 2.7.

**2.7** In contrast to the shoreline in figure 2.6, the lower energy coastline of Tawhranui faces the Pacific Ocean to the east.

Waves approaching a coastline do not distribute their energy evenly along the shoreline. We can regard each wave as a bundle of energy moving towards the shoreline. Each wave (or bundle of energy) can be divided into equal 'parcels' of energy, divided by lines drawn at right-angles to the wave crest, known as a **wave orthogonal** (figure

2.8). As each wave approaches the shoreline, it meets shallow water in front of the headlands while the water is still deep in front of the bays. The shallower sea bed slows the wave in front of the headlands, while still allowing the wave to travel more quickly into the bays. The effect of this is that waves refract, or bend, around the headlands and meet the shoreline approximately at right-angles.




**2.8** The distribution of energy along a shoreline that comprises alternating headlands and bays. Each incoming wave is divided into equal segments of energy. The wave orthogonals show that the energy is concentrated onto the headlands and dispersed in the bays. Figure 2.1 shows a real world example of this model in practice.

The pattern of the wave orthogonals shows that energy is **concentrated** on to the headlands and is **dispersed** in the bays. This uneven distribution of energy focuses erosion on most headlands, while deposition will occur in most bays. For this reason, cliffs are common on headlands while beaches will usually form inside bays.

**2.9** Alternating cliffs and bayhead beaches in Sydney, Australia.

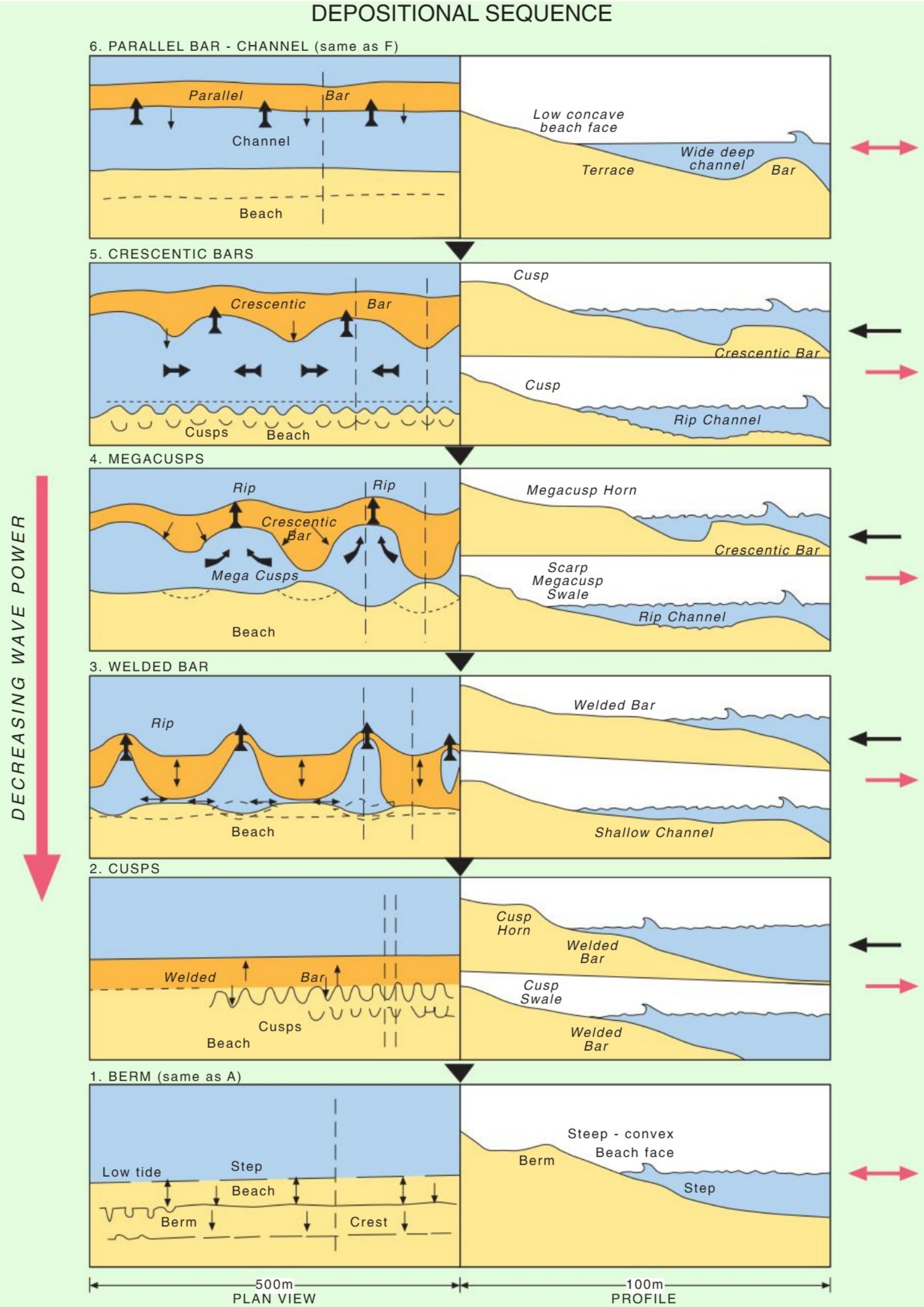
Wave refraction is also responsible for forming **tombolos**, or tied islands. If an island is located close to the coastline, waves refract round it as if it were a headland, and meet behind it. When the waves collide they lose competence to carry sediment. Deposition therefore occurs behind the island, first in the form of a cuspate foreland that eventually grows to join the island to the mainland to form a tombolo.

**2.10** A tombolo, or 'tied island'. The wave refraction around the island can be seen. This example is at Bournda in south-eastern New South Wales, Australia, which is also shown in figure 2.67.

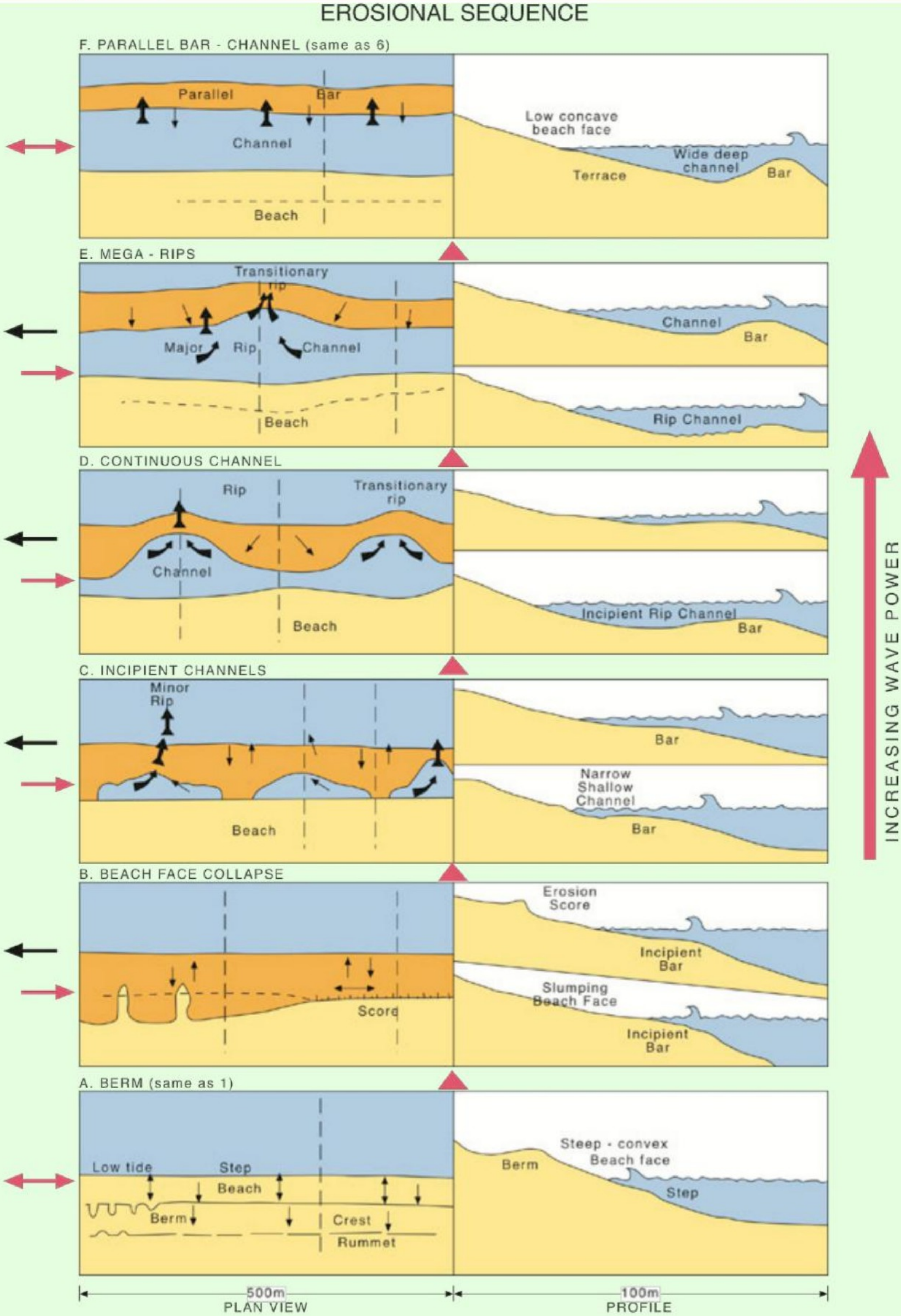
Waves can be constructive or destructive. Waves are generally **constructive** during periods of low energy, when deposition occurs. On the other hand, waves are **destructive** during periods of high energy, when erosion is likely to occur. Beaches tend to go through cycles of erosion or deposition depending on the wave energy available (figure 2.11).

In the **depositional sequence**, decreasing wave energy changes the shape of the beach from stage 6 to stage 1, unless it is interrupted by an increase in wave energy. In the **erosional sequence**, increasing wave energy changes the shape of the beach from stage A (or wherever the starting point is) through to stage F, unless interrupted by lower energy conditions.

Landforms are changed when there is a change in the levels of water, sediment or energy. **Deposition** will occur if there is an extra input of sediment. The extra sediments available will be formed into depositional landforms such as deltas, beaches, dunes and so on. On the other hand, if there is a loss of sediment, **erosion** will occur. Whether a landform is erosional or depositional depends on




**2.11** A model of beach erosion and deposition. The depositional sequence is shown on the left (i.e. this page), with decreasing wave energy from stage 6 (at the top) through to stage 1 (at the bottom). The erosional sequence is shown on the right (facing page), with increasing wave energy from stage A (at the bottom) to stage F (at the top). A beach may change from the depositional sequence to




the erosional sequence, and vice versa, at any time, as shown by the arrows between the two pages. In each stage of the sequence, the left hand diagram shows the beach in plan view from above, while the right hand view shows the cross-section. On the plan views, yellow indicates sand above the water, orange indicates sand below the water, and the dashed lines show the locations of the cross-sections.

the supply of sediment and energy available. By comparing the appearance of a beach with the model shown in figure 2.11, we can get good indication as to whether the beach is undergoing a depositional or an erosional sequence at the time.

2.12 The small welded bar on this beach on Tioman Island, Malaysia, suggests it is at stage 3 of the depositional sequence.

**Coastal erosion** occurs through three processes; hydraulic action, corrasion and corrosion.

**Hydraulic action** occurs as a result of the **impact** of waves. Hydraulic action, which is also known as **quarrying**, can be especially powerful during a storm, when large waves lash the shoreline. A 6 metre high wave can exert a pressure of more than 1 kg/cm² when it strikes exposed rock, and hydraulic pressures as high as 7 kg/cm² have been recorded momentarily when waves impact against sea walls.

Hydraulic pressure also acts **indirectly** through compression of air in cracks and fissures as a wave

2.13 The force of hydraulic action can be appreciated when we see this frontal wave attack on a sea wall in Havana, Cuba.

2.14 This severely eroded coastline in Madang, Papua New Guinea, is mainly the result of hydraulic action on a retreating coastline.

hits the rock face. This action has a similar effect to driving a wedge into the cracks in the rock. When the wave recedes, the pressure is released and the compressed air expands with an explosive force. When water is shallow, significant shock pressures are exerted when waves with a trapped air pocket break against an obstruction.

**Corrasion** (sometimes called **abrasion**) occurs when rock and sand fragments are thrown by waves against cliffs, or are rolled back and forth across the shoreline. As the rock and sand fragments rub against the rock or other surface, they **abrade** the surface, scraping or wearing it away by friction. Corrasion is most effective in the surf zone because that is where most turbulence occurs, and because there is usually an abundant supply of sediments that have either been supplied by nearby streams or which are the result of previous wave erosion.

2.15 The brown colour in these waves shows the particles of sand and sediment that are abrading the rocks as the waves wash over them in the process of corrasion.

Attrition is a process that is usually associated with corrasion. **Attrition** is the rounding or smoothing of rocks and particles that are carried by waves. The smaller fragments become, the more readily they may be moved seaward by currents, so the process of **marine erosion** is assisted by the process of attrition.

The third process, corrosion, is of minor importance on coasts compared with hydraulic action and corrasion. **Corrosion**, also known as **solution**, is the dissolving of minerals in rocks. It is most common on limestone coasts and coral reefs because limestone and coral are composed of calcium carbonate, which is soluble in water. In areas where the water is slightly acidic, the rate of corrosion is more rapid than in areas with less acidic water.

**2.16** Evidence of corrosion can be seen at the base of this limestone pinnacle on the coast of Koror, Palau. The ocean water has dissolved the rock, undercutting it and destabilising it, resulting in the collapse of some of the pinnacle (in the right foreground).

**Coastal sediment** is supplied from two main **sources**. The first is the land, which supplies gravels, quartz sand, silts and muds. These sediments may be brought to the coast by rivers, or they may result directly from the erosion of cliffs. The second source of sediments is the sea. When marine organisms die, their shells and skeletons supply carbonate sediments to the coast. We can therefore say that coastal sediments are supplied by rivers, by marine erosion, or they can be produced on site.

The twice-daily rises and falls in local sea level caused by the gravitational attraction of the sun and moon are known as **tides**. Although the moon is smaller than the sun, it is much closer to the earth and so it exerts a 2.16 times stronger gravitational force. Consequently, lunar tides are more significant than solar tides. Every two weeks, at the new and full moon, the moon is aligned with the sun, and this alignment produces the highest tides called spring tides. At the moon's first and last quarter, it is perpendicular to the sun, and lower neap tides result. When the spring tides coincide with periods of high winds or storm activity, a strong force capable of severe erosion may result.

**2.17** Streams flowing into the sea are a significant source of coastal sediments. In this photo, a large sediment load is deposited by a river entering the Java Sea on the northern coastline of the island of Java (Indonesia), east of Jakarta.

The difference between high and low tide on a particular day is known as the **tidal range**. The tidal range can vary greatly from place to place around the world. In the deep oceans, the tides

**2.18** Tidal range can have a significant impact on the shape (morphology) of coastlines. This oblique aerial view shows Tarawa, a coral reef that is part of the Pacific island nation of Kiribati, at low tide. At high tide, all the sandy area in the foreground is covered by water.

average only 18 centimetres in height. On the other hand, the height of the tides usually increases at shallow continental shelves and in coastal inlets. Depending on the shape of the sea bed and coastline, some coasts receive tides with a small range (less than 2 metres), while others receive tides over 10 metres in range. The coastline of South Wales that faces the Bristol Channel is one example of an area with a large tidal range.

## Other physical processes

### Subaerial processes

Not all the processes operating on coasts are marine processes. **Subaerial processes** are those processes that occur in the open air or on the surface rather than underwater. The atmosphere plays a very important part in these processes.

We have already seen that winds generate ocean waves, which provide most of the energy that leads to change in coastal environments. The role of the atmosphere in coastlines is much greater than this, however. The atmosphere produces **precipitation**, which in turn leads to **weathering** of rocks. Together with the force of gravity, subaerial processes produce and deliver **sediments** that are then available to be rebuilt into beaches, deltas and continental shelves in the coastal zone.

Atmospheric processes shape the land's surface by **reworking** marine sediments and chemicals in areas well above the reach of the waves and tides. The wind provides energy to blow beach sand inland to form **dunes**. In tropical areas, temperature influences the growth of coral and algal organisms that produce the **coral reefs** on many coasts. **Temperature** also affects plants (such as mangroves and salt marsh plants) and animals of the inter-tidal zone in the mid-latitudes. Furthermore, atmospheric forces play a role in the polar latitudes; when the sea temperature falls below –4°C the water freezes, forming **sea ice** that stops most landform formation activity on the coastline.

2.19 Coastal sand dunes form as a result of sub-aerial processes, not marine processes. Specifically, wind provides the energy required to blow beach sand inland.

### Biological processes

The most important biological contribution to coastal landforms is the supply of **calcium carbonate** sediments from the skeletons and shells of marine organisms. This occurs especially in tropical and temperate regions of the world. In the tropics, reefs of coral and algae are important in influencing the development of the coast. In other areas, the plants and animals of the coastal dunes, rocky coasts and inter-tidal regions all contribute sediments. Some marine organisms that grow in the inter-tidal zone of rock platforms contribute to the breakdown of their host rock by secreting acidic wastes. As a general rule, biological influences on the coast decrease towards the poles.

2.20 Periwinkles graze on various types of algae on the rock platform, but their wastes help to break down the rocks.

### Chemical processes

**Chemical processes** tend to be related closely to weathering caused by atmospheric processes. Nonetheless, there are some additional and unique effects that are found in the coastal zone. **Salt spray** carried by the wind speeds up weathering and the breakdown of the coastal land surface. As the salt

2.21 Honeycomb weathering in rocks on the island of Tung Ping Chau, Hong Kong.

water evaporates, the dissolved salt forms crystals in small cracks and pores in the rock. As the crystals grow, they can cause the fracturing of the rock. Salt crystallisation often leads to a distinctive pattern of **honeycomb weathering** in coastal areas where evaporation rates are high.

In warm tropical waters in the inter-tidal zone of many beaches calcium carbonate is precipitated, cementing the sand grains together to form **beachrock**. In warm to hot semi-arid regions, calcium carbonate cements the grains of coastal sand dunes together to form **dune-rock**.

2.22 Elevated beachrock at Tamarindo, Costa Rica.

### Question Bank 2A

1. *What does the term 'marine processes' mean? What other processes affect coastal terrains?*
2. *In what ways do waves change as they approach the shoreline? Why do these changes occur?*
3. *Explain why wave energy is unevenly distributed along a coastline. What are the effects of this?*
4. *Draw a diagram to show the relationship between wave height and wave length.*
5. *How are waves formed?*
6. *What determines whether a coastline will experience erosion or deposition?*
7. *Describe the changes seen on a beach as it progresses through (a) the depositional sequence, and (b) the erosional sequence.*
8. *Describe the three processes that lead to coastal erosion.*
9. *Describe the non-marine physical processes that affect coastal terrains.*

# Coastal landforms

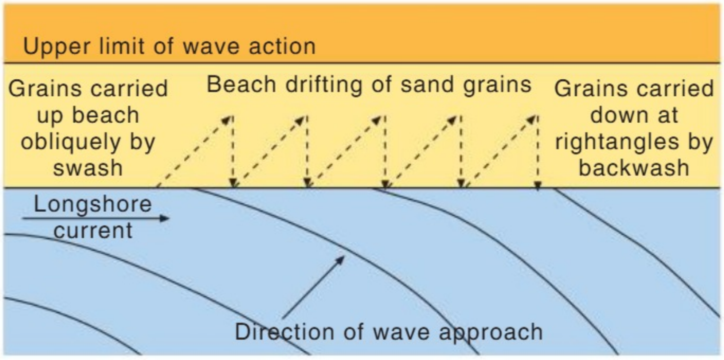
## Depositional landforms

Depositional landforms cannot form unless **three conditions** are met. First, the inputs of sediment must exceed the losses. Second, the coastal processes must be operating to transport and deposit the sediment. Finally, the existing surface must be suitable to receive or mould the sediment. Of these three conditions, the coastal processes are probably the most important, and we will focus on these in this section. We will look first at beaches and dunes built by waves and wind, and then we will explore estuaries and deltas built by tides and rivers.

### Beaches

A **beach** is the accumulated sediment deposited by waves on a coast. Where beaches occur at the head of a bay, they are known as **bayhead beaches**; if they occur on the side of a bay, they are known as **bayside beaches**. Beaches form when water moving onshore brings and deposits sediment. The water that moves up a beach after a wave has broken is known as **swash**, while **backwash** is the water returning to the sea from the beach.

If the waves approach the beach at right angles to the shoreline (which is sometimes called the wave-sediment interface), the backwash will return to the sea at the same place as the swash went up the beach. In this way, a grain of sand being moved by the water will be returned to its original position. On the other hand, if the waves hit the shoreline at an angle, then the swash will go up the beach at that same angle, but the backwash will return along the steepest route, straight down the beach. In this way, a grain of sand may be moved along the beach. This process, known as **longshore drift** or **littoral drift**, can go on for many years, during which time a significant amount of sediment can be moved along the beach in one direction. On some shorelines, longshore drift causes so much movement of sediments that barriers called groynes are erected to trap the moving sands.




2.23 The process of longshore drift or littoral drift.

2.24 Groynes built to impede longshore drift, Virginia Key, near Miami, USA.

2.25 A boulder beach on Vatia Bay, American Samoa.

Beaches usually consist of sand and / or gravel, although sometimes they are built of boulders, in which case they are called **boulder beaches**. Boulder beaches are usually found in high-energy environments where all the sand-sized particles have been removed, leaving only the heavier boulders. They can also occur where the supply of sediment is restricted for some reason.

As we saw earlier when referring to figure 2.11, beaches form from sediment that lies just off the shoreline in an underwater reserve called an **offshore bar**. When beaches erode during storms, the sand is moved off the land and is stored in this offshore bar. When beaches build up during times of calm weather, sand from the offshore bar moves onto the beach.

Most beaches are made up of two main sections. Beside the water is the **beach face**, which is the steeply sloping section against which the wave swash and backwash move up and down. The

2.26 A steep beach face leads up to the near-horizontal berm on Khalaktriskiy Beach in Russia.

second part of the beach is the **berm**, which is nearly horizontal and consists of sediments deposited by the swash. As we shall see later in this section, some beaches have a third zone of **dunes** behind the berm.

Some other features are often found on beach faces and berms. One such feature is **cusps**. These are regularly spaced crescent-shaped 'horns' that are deposited on the beach face by wave action. The spacing between the ridges, or cusp horns, is usually 15 to 30 metres, and each ridge is separated by a depression called a **cusp swale**. Sometimes, much larger cusps form with a spacing between 150 and 300 metres. These are a different type of feature, formed by deposition in the lee of crescentic bars, and they are called **megacusps** (see figure 2.11 earlier in the chapter).

**2.27** Cusps on a welded bar of coarse sediment between two groynes on Playa Agua Dulce in Lima, Peru.

**2.28** This small beach (Praia Vermelha) in Rio de Janeiro, Brazil, has well-formed beach cusps. The backwash that helps to form the cusps can be seen clearly in this view.

**Wave height** is the main determinant of the **shape** of a beach. Low waves (one metre high) tend to form **low energy beaches**. This means that waves surge at the shoreline forming a small 'step', and then rush up the beach face and return as backwash. Often, the backwash is then reflected up onto the beach by incoming waves. Low energy beaches are found in well protected bays and on open beaches after weeks of low waves.

**2.29** A low energy beach, Galveston Island, on the Gulf of Mexico, USA.

Where moderate waves occur (one to two and a half metres high), **medium energy beaches** form. These have **rip currents** along them, which are formed by the return flow of water 'piled up' against the shore by incoming waves. Rips are seaward moving currents of water that transport sediments beyond the surf zone. In between rip currents, **shallow bars** extend into the sea. Rips are a constant danger to swimmers as they can drag people out to sea away from the safe and shallow area of the beach.

**2.30** A medium energy beach on Tioman Island, Malaysia.

**High energy beaches** are produced by high waves (over two and a half metres). High energy beaches tend to have a steep beach face and a wide surf zone. They have **long channels** and **parallel offshore bars** that form a reservoir of sand, which is available to move up onto the beach during a depositional sequence. This reserve of sediment begins to move onshore during calm conditions, although as shown in figure 2.11, the bar does not move forward in one continuous line – instead, 'fingers', or protrusions, of the offshore bar begin to move onshore. These fingers are more or less at right-angles to the shoreline, and they occur at intervals about 150 to 300 metres apart.

**2.31** A high energy coastline that has suffered significant erosion, Accra, Ghana.

These fingers are termed **crescentic bars**, and they can be defined as ridges of sand more or less at right angles to the shoreline comprising the sediment moving from the offshore bar to the beach during a depositional sequence. As the crescentic bars attach to the shore, they become welded onto the beach. In this way, the beach moves from a high energy to medium energy state. The areas where the crescentic bars are moving onshore later become the **megacusps**, separated from each other by rip channels.

When all the sediment in the offshore bar has moved up onto the beach, the beach will have become a low energy beach. Cusps may remain as a 'reminder' of where the bars moved onshore, and the beach face will be very steep because of the large amount of sand stored there. Low energy beaches have either a very small offshore bar or none at all.

## Barrier systems

Beaches, dunes and beach ridges are all parts of a large barrier system. **Barriers** are strips of sediments joining two headlands, or lining the head of a bay, or forming a strip across the mouth of a bay.

Depending on the surface of the coast, **four types** of barriers may occur. **Bayhead barriers** rest against the mainland, and are often called beaches. **Mid-bay barriers** link two headlands and are backed by a lagoon, or in some cases, the barrier joins an island to the mainland. **Baymouth barriers** join the outer points of two headlands, and often form a lagoon as a consequence. Finally, **barrier islands** are long sandy islands that are parallel to the coast and lie seaward of it.

**2.32** The mid-bay barrier of Palm Beach joins the island of Barrenjoey to the mainland on the northern outskirts of Sydney, Australia. In the background is the ria (drowned river valley) of Broken Bay.

**2.33** A well developed barrier island on the southern coast of Liberia, east of Harbel.

Depressions that are usually filled by a **lagoon** are found behind all types of barriers except bayhead barriers. Sometimes, these lagoons are difficult to see as they have become partly or wholly filled by sediments and marsh vegetation over time. Those lagoons that are not filled are often connected to the sea by an inlet. Lagoons exit into the ocean where the incoming waves offer the least resistance, such as at one end of a beach where it might be protected from the incoming waves by a headland or a rock platform.

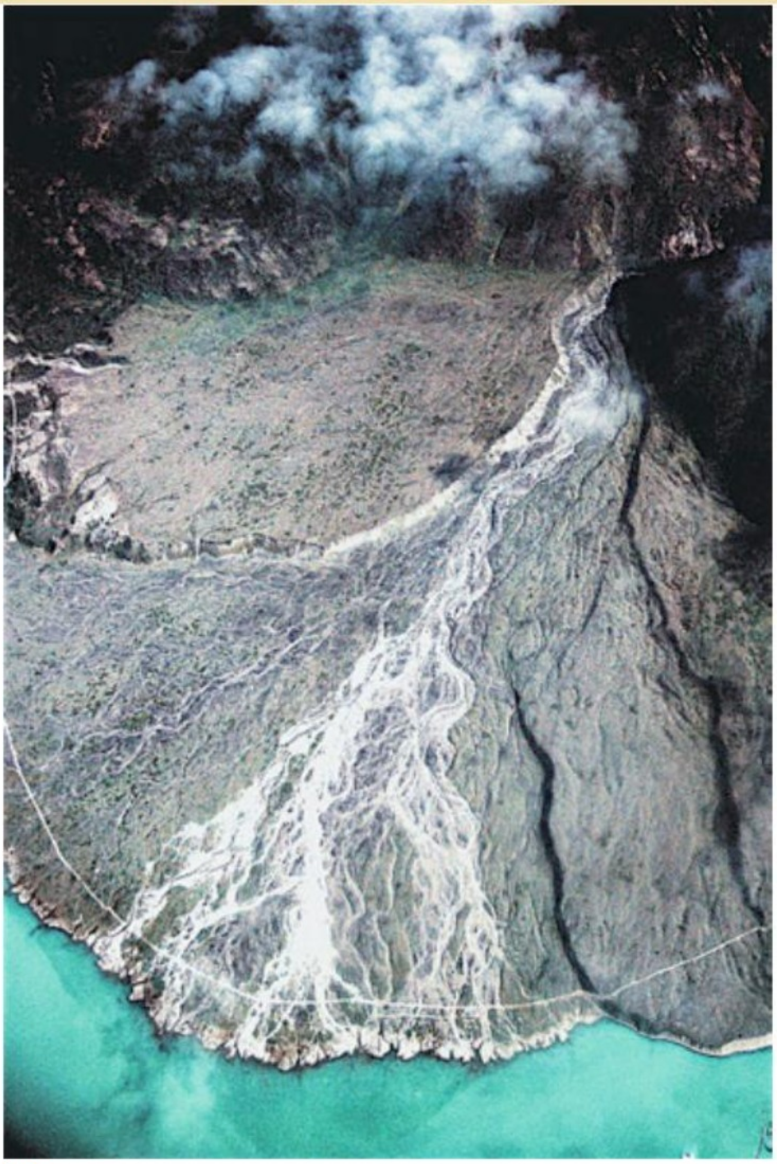
2.34 A series of coastal lagoons formed on the Central Coast New South Wales (Australia) when a rise in sea level at the end of the last ice age pushed sediments landwards to form a long coastal barrier. The two lagoons in the centre of this oblique aerial view are Budgewoi Lake (left) and Lake Munmorah (right).

When a barrier, or any strip of sediment, is only joined to land at one end, it is known as a **spit**. Spits may form as a result of longshore drift, or they can form behind offshore islands or reefs where wave refraction and lower wave energy cause the beach to build out seawards. If the spit advances to reach the island, a **tombolo** is formed.

## Deltas

**Deltas** are deposits of alluvial material at the mouth of streams or rivers. They are made up of both land sediments and biological remains that are deposited where the river enters to sea, lake or lagoon. Several major world rivers have deltas at their mouths, and examples include the Nile, Mississippi, Irrawaddy and Mekong.

Deltas are named after the Greek letter delta (Δ), because the classic shape of a delta is triangular. However, deltas may form in many different shapes depending on how much sediment is available, the coastal processes and the shape of the coastal surface. As with beaches and barriers, it is the coastal processes that exert most influence.



2.35 This arcuate delta has formed on the south-western coastline of Greenland, near Narsarsuaq.

Deltas with the classic shape most similar to the Greek letter delta are called **arcuate deltas**, and these have smooth shorelines and slightly protruding river mouths. They occur where the waves have moderate energy and so can realign the river's sediments. The Nile and Niger Rivers in Africa have formed arcuate deltas.

**Birdsfoot deltas** have quite a different shape, with highly extended channels and levees, often shaped like a bird's foot. They form where the waves are of low energy, such as where a river flows into a calm lagoon or a bay. Large marshes and mud flats are usually found between the channels. The Mississippi delta in the United States is a classic example of a birdsfoot delta.

**2.36** This small birdsfoot delta has formed in a coastal lagoon south of Nowra, on the south-east coast of Australia.

Streams flowing into coastal lagoons will sometimes form a similar feature called a **cuspate delta**. Cuspate deltas form when the waters of the stream enter the lagoon and the sediments carried by the stream are deposited. The velocity of the water is slowest near its edges, and so when the creek meets the still water of the lagoon, sediment is deposited at the edges first. Over time, the edges of the creek build out as spits of sediment into the lagoon.

**2.37** A cuspate delta has formed as Dora Creek flows into Lake Macquarie, a coastal lagoon south of Newcastle, New South Wales, Australia. Note the grey-brownish colour of the water where the concentration of sediments is high.

### Question Bank 2B

1. *What is meant by the terms 'swash' and 'backwash'?*
2. *With reference to figure 2.23, describe the process of longshore drift.*
3. *Explain why offshore bars are important in maintaining sand on beaches.*
4. *List in point form the main features you would look for in the field to recognise a high, medium or low energy beach.*
5. *How does sand move onshore? What do (a) rips and (b) cusps tell us about this movement?*
6. *Why are sand dunes important?*
7. *Draw sketch maps to show the four types of coastal barriers.*
8. *What causes a barrier to advance, recede or stay still?*
9. *What is a spit? How can a spit become a tombolo?*
10. *What is a delta? Sketch the three types mentioned.*
11. *Make a point form list of depositional coastal landforms.*

## Erosional landforms

Erosional landforms form when there is a **net loss** of **sediment** from a coastal system. Erosion may also result when the input of **energy** or **water increases**, such as during a period of storms. Sometimes the landforms eroded may be former depositional landforms, such as barriers and deltas, which are now losing sand. On other occasions, they may be formed by direct erosion of the coastal rock surface.

When depositional landforms begin to erode, it indicates that there must have been a reversal in the **inputs of sediment**. Many forces could lead to this situation. A decline in the supply of sand from rivers could lead to erosion. Alternatively, less sand may be available from the continental shelf. Sand may have been lost to longshore drift, flood tide deltas in estuaries and coastal sand dunes. During very severe storms, sand may be removed out beyond the offshore bar and wave base. When this happens, it is 'lost' to the coastal system as it cannot be brought back by wave action.

A low energy beach, which has the sand from the offshore bar up on the beach, is easily eroded during heavy seas. As the wave height increases, **small channels** are eroded in the beach face which carry water and sediment offshore. In very heavy seas, the waves may erode a **scarp** in the beach face. As shown in figure 2.11 earlier in this chapter, erosion continues and the sand moves offshore in **crescentic bars** similar to those used when the sand moved onshore, except that they are much further apart (about 200 to 500 metres). **Megacusps** form, with rip channels between the horns marking where sand is being taken offshore. If the heavy seas continue long enough, a high energy beach will be formed with much of the beach sediment in the **offshore bar**.

## Processes operating on rocky coasts

Rocky coasts usually contain steep sea **cliffs**. If a cliff has retreated landward, a **platform** extending seaward from its base will also be present. The seaward edge of the platform marks the original seaward edge of the cliff. The level of the shore platform depends on the rock type and the exposure to wave attack, but it is usually somewhere between the low tide level and up to about 3 metres above sea level.

The processes that cause the cliffs to **retreat** are the most important processes on rocky coasts. These processes are both **physical** and **chemical**. Rocky coasts are exposed to all the normal weathering processes that occur in humid terrains in addition to the specific coastal impacts of salt spray and wave attack. The marine forces acting on cliffs include the continual wetting and drying effects of spray, swash and tides, and the physical attack by waves and stones carried by waves.

2.38 A wave-cut platform on the seaward edge of this cliff at Llantwit Major Beach in South Wales, UK, shows the original extent of the cliff before it receded by erosion.

2.39 These cliffs and wave-cut platforms on St Donat's Bay, South Wales (UK) have been formed in shale rock of loosely structured horizontal layers. The effects of undercutting the cliff by wave action at high tide can be seen.

These processes reach maximum efficiency just above sea level when they act together. For this reason, the greatest degree of **weathering** occurs immediately above the level of permanent saturation of the rock. Below this level, chemical weathering processes are restricted because of the lack of free oxygen. Above this level of saturation, however, chemical weathering is accelerated greatly by the continual wetting and drying and the action of salt spray.

So, a zone of **rapid weathering** occurs just above the level of saturation on many rocky coastlines. In this zone, the weakened rock fragments are then easily removed (eroded) by wave attack. As the cliff is eroded and undercut, rocks fall and slide downwards to the cliff base or platform, where it collects as **talus**. Talus (also known as **scree**) is the build up of rock debris at the foot of a cliff. During storm times when wave energy is greatest, the talus may later be removed by wave action.

**Wave quarrying** is a specific process that acts on rocky coasts. This involves the physical removal of rocks from the cliff face or platform by direct **hydraulic action**, usually by waves quarrying out the rocks along joint or bedding lines. Rocks weighing several tonnes can be removed in this manner, and it is the main form of erosion of the seaward edge of the platform. It is particularly common in the jointed and layered rocks such as sandstones and shales.

As we saw earlier in the chapter, **corrasion (**or **abrasion**) is the wearing away of the rock surface by rocks and sediments carried in waves. On rocky coastlines, the rocks and sediments carried in the waves are called **toolstones**. They are rolled and dragged across the surface, physically abrading (wearing away) themselves and the surface. This leads to a rounding of the toolstones and smoothing and polishing the rock surface. A special form of abrasion can lead to the formation of potholes. **Potholes** are eroded by rocks that abrade downwards, and often outwards, to form steep-sided depressions in the surface of the rock platform. When abrasion combines with salt crystallisation, **differential weathering** can occur leading to strangely shaped formations, such as the **pedestal rocks**.

2.40 Pedestal rocks formed in sandstone at Yehliu on the northern coast of Taiwan. Wave quarrying has broken up the sandstone along joint lines, and salt crystallisation has caused honeycomb weathering. Abrasion has eroded the base of the resistant pillars of rocks, causing the pedestal formations.

**Organisms** that inhabit the intertidal zone have a mixed impact on rocky coastlines. On one hand, their presence provides **protection** against abrasion and drying out. On the other hand, they may also **erode** the rock surface by their own actions. Boring organisms and those that graze on the rock surface can produce local but severe erosion. Sea urchins are very effective in eroding soft rock layers underwater.

**Biological processes** become increasingly important in the warmer waters that are found towards the equator. In cold climates, on the other hand, sub-zero temperatures cause water to freeze in the rock joints, producing frost wedging and eventual shattering of the rock surface.

## Landforms of rocky coasts

Large-scale features on rocky coasts include the sea cliff and shore platform, as described in the previous section. In certain rocks that are soft or which have lines of weakness, the cliff may be stranded seaward to form **sea stacks**. An earlier stage in the formation of stacks is when they remain connected to the mainland or to each other, but are being undermined by sea caves linking together.

2.41 The Twelve Apostles, a collection of stacks near Port Campbell, Australia.

2.42 Sea arch, Port Campbell, Australia.

2.43 A blowhole erupting at Muriwai, New Zealand.

This stage produces a landform called the **sea arch**. If arches, stacks or cliffs are undermined, such as when waves quarry along a joint of line of weakness in the rock, a **blowhole** may form.

Cliffs often possess **ledges**, which are layers of rocks that are more resistant to weathering. Often the top of the cliff will consist of a resistant layer of rock that protects the cliff from erosion from above. Where this occurs, the vertical shape of the cliff is maintained by wave action undercutting the rocks above. If the base is eroding rapidly, a **notch** may be cut into the base, which may lead to further undercutting and undermining of the cliff. Many 'notches' coincide with weaker bands of rock, and are not at wave level.

Platforms sometimes rise towards their seawards edge where a **rampart** (a raised 'lip') is found. The rampart occurs because that part of the platform is more saturated than other parts of the platform due to the constant wave wetting, unlike the rest of the platform which experiences a constant cycle of wetting and drying due to tidal changes. For this reason, the edge of the platform is not subject to the continual wetting and drying that accelerates weathering.

2.44 Looking towards the ocean on this wave-cut platform in Tamarindo, Costa Rica, the waves can be seen breaking over the rampart, or constantly saturated raised lip, on the seaward edge of the platform.

Several factors work together to encourage the development of **shore platforms**, including:

- warm to temperate climates which encourage wetting and drying;
- moderate to high wave energy to remove cliff debris;
- a small tidal range to concentrate the level of saturation and erosion;
- sedimentary and metamorphic rocks (or basalt), as these are porous and permit saturation and rapid chemical weathering; and
- horizontally bedded rocks with heavy jointing.

In general, platforms do not form on granites and other massive rocks, especially when they are in protected areas of low wave energy.

## Question Bank 2C

1. *What factors lead to coastal erosion?*
2. *What could cause the supply of sediment on a coast to decline?*
3. *Referring to figure 2.11, describe the stages in the erosion of a beach due to high waves.*
4. *What does the presence of a shore platform tell you about the cliff next to it?*
5. *At what height is weathering concentrated on the coast? Explain why this is so.*
6. *What is the difference between the processes of wave quarrying and abrasion?*
7. *Describe the stages in the erosion of a cliff to form a sea stack.*
8. *Explain the reasons for the different shapes of the cliffs shown in figures 2.38 and 2.39.*
9. *List the factors that assist formation of shore platforms.*
10. *Make a point form list of erosional landforms.*
11. *Select one photograph from this chapter that shows several coastal landforms. Draw a full page photosketch of the photograph, labelling the significant coastal features of the area shown. Choose two of these features and explain their formation.*
12. *'All landforms are the result of erosion and deposition.' Discuss this statement with reference to coastal landforms.*
13. *Name and locate a coastal terrain you have studied in the field. With reference to three landforms, discuss the processes operating in the area.*

# Advancing and retreating coastlines

## Processes of advance and retreat

Coastlines seldom stay in the same place over long periods of time. Coastlines are constantly advancing and retreating as erosion and deposition occur. When a coastline endures a sustained period of retreat, it is classified as a **retreating coastline**. Coastlines retreat (or give way to an advancing ocean) when the land subsides relative to the sea. This may occur either because the sea level rises or because geological changes lower the land relative to the sea. Coastlines may also retreat because the rate of erosion exceeds the rate of deposition.

A coastline is classified as an **advancing coast** if deposition exceeds erosion for a sustained period of time. Alternatively, a coastline advances when a shoreline emerges from the sea, either because the sea level falls or tectonic uplift raises the land.

When coastlines advance or retreat due to a rise or fall in the sea level, it is known as a **eustatic** change. When the eustatic change is caused by melting or freezing of polar caps or glaciers, it is known as a **glacio-eustatic** change. If the change in sea level is the result of a change in the shape of the ocean basin, then it is a **tectono-eustatic** change.

**2.45** An emerging, or advancing, coastline. Although this raised beach in Rhossili (Wales, UK) is now used for farmland, it is evidence of a glacio-eustatic rise in the land.

**2.46** Erosion of the dune system of this beach at Surfers Paradise (Australia) shows that this is a retreating coastline where the rate of erosion exceeds the rate of deposition.

**2.47** Evidence that the coastline at Banjul, Gambia, is retreating is shown by the undercut and collapsed land, and the baobab tree that has fallen with the collapsing land.

## Sea level (eustatic) changes

The earth's temperature has risen and fallen on many occasions over the past few million years. In general, these changes in temperature are just a few degrees Celsius. During the cooler periods, called **glacial periods**, much of the world's water is stored in glaciers and continental ice sheets, resulting in a **lowering** of world sea levels. During warmer periods, called **interglacials**, this trapped water is released once again into the world's oceans, causing a **eustatic rise** in sea levels.

The changes in sea level resulting from these changes in temperature have been between 100 and 150 metres during the last two million years. At present the earth is relatively warm compared with past times, so the world's ice sheets are smaller than their average sizes, and sea level is also higher than average. Indeed, at the end of the last great ice age only 11,500 years ago, the world sea level was about 125 metres below the present level. At that time, most of the world's shorelines lay near the edge of the continental shelves. The previous occasion when sea levels were as high as now was about 120,000 years ago.

The last ice age, called the **Pleistocene**, ended about 11,500 years ago. At that time the large ice sheets began to melt, causing oceans to rise to their present levels. This process took some time to complete, and the oceans continued rising until about 6,000 years ago. This post-glacial rise in sea level was called the **Holocene**, and because it was very recent in geologic time, almost all of today's coastal landforms are very young, being 6,000 years old or less. All the older coasts were submerged out on the continental shelf, except the old coastal features formed around 120,000 years ago.

As the sea rose across the continental shelf between 11,500 and 6,000 years ago, it swept along with it many of the sand size sediments lying on the shelf, such as soils, river beds, old beaches and dunes. These sediments were reworked and moved inland with the rising waters, and eventually they were deposited along the present shoreline. As a result of the most recent rise in sea level, the continental shelf has been a major source of coastal sediment. This is particularly so in areas with moderate to high waves, such as the southern half of Australia.

With the rise in sea level, many coastal valleys were drowned. This formed deep estuaries such as the **fjords** in the formerly glaciated U-shaped valleys of Norway and New Zealand, and drowned river valleys (or **rias**) in temperate countries. Because the fjords and rias are very young in geological terms, the rivers which flow into them are still depositing their coarser materials (sand and gravel) in the upper reaches of the estuaries rather than at the coastline. At the same time as this is happening, waves and tides are pushing sediments up into the estuaries, and the sediments are lost to the coastal system. In this way, many coastal estuaries are acting as **sediment sinks**, trapping sediment that would otherwise be available at the coast. This will continue until sediments fill the estuaries and the rivers can flow directly to the coast.

If natural cycles were to operate, we would expect the world's sea level to begin falling in the next few thousand years. However, changes in the atmosphere brought about by **human activities** such as pollution could upset this balance. If temperatures were to rise as a result of human impact on the atmosphere, and the Greenland and Antarctic ice sheets both melted, sea level could rise by 70 metres, drowning all the world's ports and most coastal cities.

## Isostatic changes

Not all sea level changes are the result of current climate change. Sometimes the land will rise or fall because of local **tectonic** pressures, or changes in the earth's crust. Unless an area is compared with other areas, it is difficult to tell in the field whether it is the land or the sea that has changed height. If the land has risen relative to the sea, then **raised beaches** may result. When a raised beach has a cliff behind it that it now higher than the zone where marine processes currently operate, it is said to be a **relict cliff**.

Some tectonic changes occur as a lag effect of earlier changes in the earth's climate. According to the theory of **isostasy**, the earth's solid crust 'floats' on the liquid mantle beneath it. Like any solid that is floating on a liquid, larger land masses that rise to great heights above the level of the liquid (mountains) will protrude more deeply into the liquid beneath (the mantle) than land with a lower elevation.

**2.48** Milford Sound in New Zealand is an example of a fjord.

**2.49** The dendritic shape of Middle Harbour (foreground) and Sydney Harbour (midground) in Australia show the typical shapes of rias, or drowned river valleys. In contrast, the inlet in the background with the round shape (Botany Bay) is not a ria, but a depression that formed by the slumping of sediments. The two parallel intrusions of land into Botany Bay are human features (the runways of Sydney Airport).

During the last great ice age, vast areas of northern Europe were covered in a layer of ice that was, in places, as thick as three or four kilometres. The weight of this ice on the land acted like an additional layer of rock, pressing downwards on the land on which it lay to force it deeper into the liquid mantle.

When the ice age ended about 11,500 years ago, the ice melted and sea levels rose over the next 5,500 years, a process that ended only about 6,000 years ago. However, it took much longer for the land that had been forced downwards to rise again after the mass of the ice sheets had been removed. Indeed, this process of **isostatic readjustment** is still occurring today in parts of northern Europe, resulting in emergent (or advancing) coastlines.

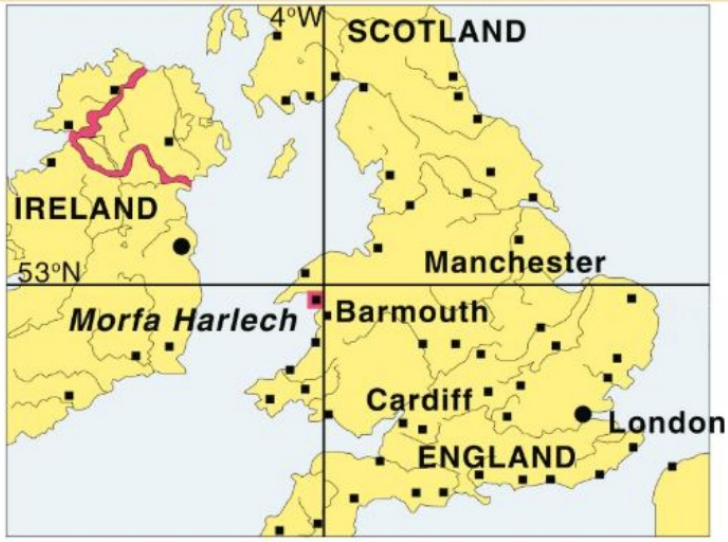
## Question Bank 2D

1. *What are retreating coastlines, and how do they occur?*
2. *What are advancing coastlines, and why do they occur?*
3. *What is the difference between the terms 'eustatic' and 'glacio-eustatic'?*
4. *How typical of the planet's history are the world's current sea levels?*
5. *Explain the causes of sea level change.*
6. *Describe the processes that form (a) raised beaches, (b) fjords and (c) rias.*
7. *What are the two main sources of coastal sediments? What role has sea level change played in creating them?*

## CASE STUDY
## Morfa Harlech. North Wales

Morfa Harlech is a **sandy peninsula** immediately north-west of the town of Harlech, which is in turn located 16 kilometres north of Barmouth on the western coast of North Wales. It is part of Snowdonia National Park, and south-east of Llanfairpwllgwyngyllgogerychwrndrobwllllantysiliogogogoch, a town famous for its long name. Harlech's precise location is latitude 52˚52'N and longitude 4˚07'W.

Much of the sandy peninsula of Morfa Harlech is covered with **large sand dunes**. The sand which makes up the dunes comes from two main sources. The more important source is a large supply of sand which was deposited off the coast south of




2.50 The location of Morfa Harlech.

Morfa Harlech at the end of the last ice age about 11,500 years ago. This sand has been moved northwards by **longshore drift**, caused by waves created by the prevailing south-westerly winds blowing in from the Atlantic Ocean. The sand is deposited at Morfa Harlech because this is the point at which the coastline **changes direction** abruptly from north-south to east-west.

2.51 This river is the Afon Glaslyn, a major source of sediments for the sandy peninsula of Morfa Harlech. As shown on the map in figure 2.54, it flows into the sea between the towns of Morfa Bychan and Morfa Harlech at the point where the east-west coastline to the west of Morfa Bychan turns into a north-south coastline around Morfa Harlech. The sediments are deposited onto the river's banks and Morfa Harlech peninsula as the flow of the river is slowed by the incoming ocean waves.

The second source of sand is two small rivers which join together and flow into the sea at the point where the north-south coast turns to become east-west. These rivers, known as the Afon Glaslyn and the Afon Dwyryd (Afon is Welsh for 'river'), bring sediments from the hilly areas inland of Morfa Harlech. When the rivers meet the sea, their

**velocity is slowed** down and they lose the capacity to carry their sediments, depositing them around the mouths of the streams. Once sand is deposited, the **prevailing winds** form dunes around small obstacles, and these dunes then grow in size as more sand is deposited in the area. Once vegetation establishes on the dunes, they become **stabilised** and increase in size.

2.52 A view of Morfa Harlech showing sand dunes that have built up behind the sand flats on the south-western side of the peninsula.

Morfa Harlech was affected by the last **ice age**. Like most of northern Europe, the area of Morfa Harlech was covered in a thick sheet of ice during the last great ice age, known as the **Pleistocene**, which ended about 11,500 years ago. When the ice age ended and the ice melted, the glaciers and ice caps retreated and the melting water flowed into the oceans, raising the world's sea levels.

In North Wales, the **retreat** of the ice cap led to the **raising** of the land due to **isostatic readjustment**. When the ice sheets covered Morfa Harlech, their immense weight forced the land downwards into the liquid mantle upon which the solid crust of the earth 'floats'. When the ice melted, the land rose, but because of the **lag effect**, the crust is still rising now 11,500 years after the Pleistocene ended. The effect of isostatic readjustment in Britain is that the island as a whole is slowly **tilting**. The north-west of England (which was covered in ice) is slowly rising, meaning that this is an advancing, or emerging, coastline. On the other hand, the south-east of England (which was not covered with ice) is slowly sinking, making this is a zone of retreating coastlines. The sinking in the south-east has been responsible for problems such as increased flooding in London and flooding in the Norfolk Broads.

The rising level of the land at Morfa Harlech has an impact on **vegetation**, which in turn affects the formation of **sand dunes** and other landforms. In summary, the rising level of the land:

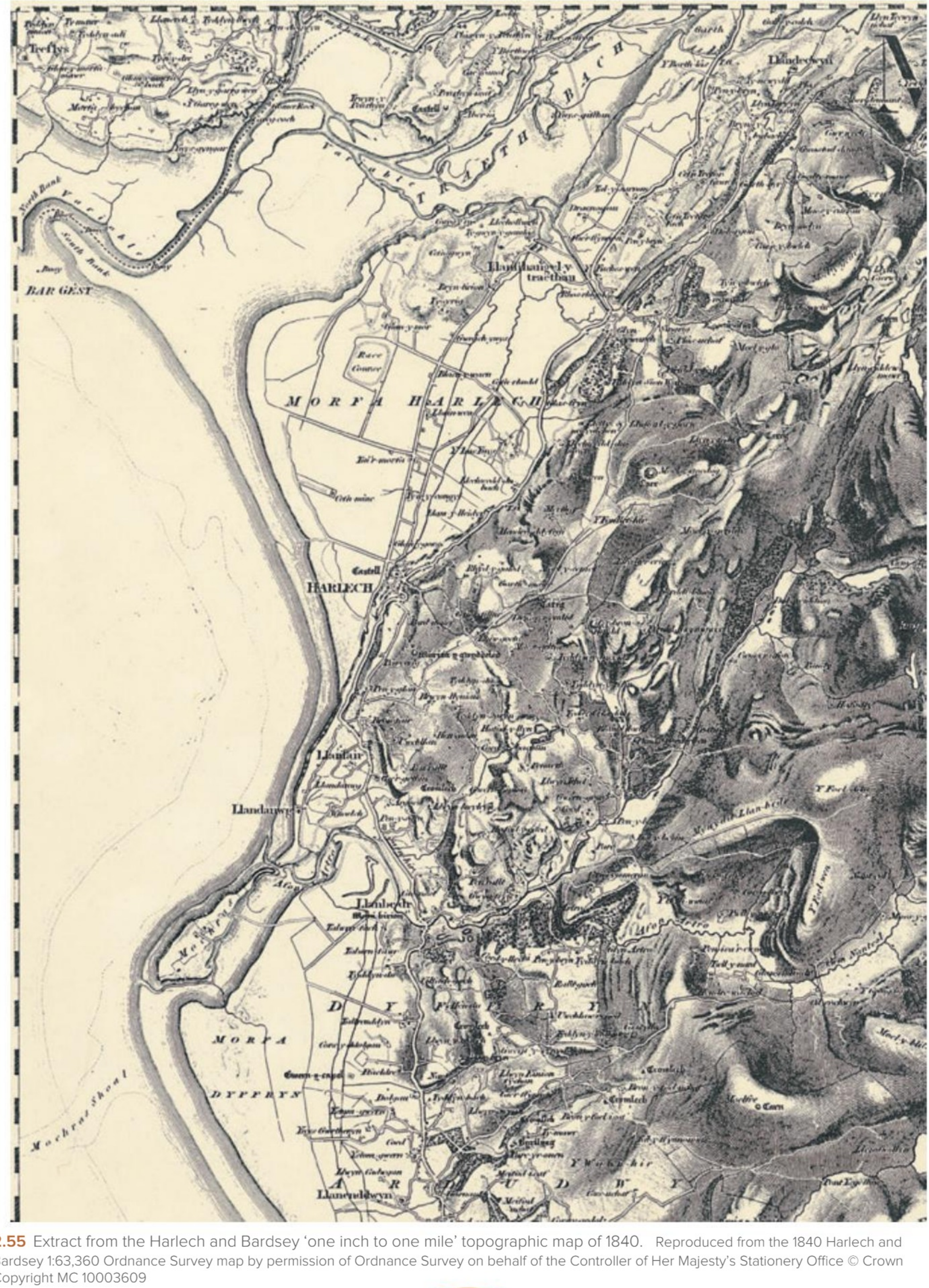
- constantly **exposes new sediments** from beneath the ocean, which are then available for **colonisation** by plants (primary producers);
- causes the coastline to **advance** into what used to be the ocean, meaning that sea dependent plants find themselves further away from the environment to which they have adapted and which sustains them (the sea); and
- **elevates** the land, exposing plants to the elements more than previously, especially to fierce onshore winds from the North Atlantic Ocean, which also have the effect of **destabilising** the sand dunes and forming **blowouts**.

2.53 Blowouts in the sand dunes of Morfa Harlech. The area in the foreground is the Royal St David's Gold Course, built across the sands of the Morfa Harlech National Nature Reserve.

The changes occurring at present are due to a **continuing rise in land level**. We know that it is the land at Morfa Harlech which is rising and not the sea that is falling because there is no global fall in sea level at present. The coastline at Morfa Harlech is therefore continuing to advance into the sea. This means that the youngest sand dunes are found closest to the sea, with older sand dunes inland.

The vegetation that colonises the sand dunes at first are salt-tolerant (or **halophytic**) grasses. This is because the sand in the young sand dunes still contains salt residues from the ocean water. As the halophytic grasses grow, they remove salt from the


2.54 Extract from the Dolgellau 1:50,000 topographic map showing Morfa Harlech, 1995. Reproduced from the 1995 Dolgellau 1:50,000 Ordnance Survey map by permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown Copyright MC 10003609




**2.55** Extract from the Harlech and Bardsey 'one inch to one mile' topographic map of 1840. Reproduced from the 1840 Harlech and Bardsey 1:63,360 Ordnance Survey map by permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown Copyright MC 10003609 sand, they add humus to the soil that develops, and they stabilise the sand to form less exposed, more sheltered environments in the swales of the dunes.

The main vegetation species on the foredunes at Morfa Harlech is **marram** grass, a tough grass with long, sharp leaves which can roll in on themselves to reduce transpiration and spikes to make them unappetising to grazing animals. It has long roots which grow quickly, thus being able to bind together and stabilise the shifting sand of sand dunes. The marram grass is one of the few species that can grow in salty sand, and as it grows it removes salt from the sand and adds humus. This prepares the way for other species such as low scrubby bushes to replace the marram grass on older dunes.

**2.56** Marram grass on dunes at Morfa Harlech. Note how the grass stabilises the sandy dunes, protecting the dunes from wind erosion.

**Human activity** in Morfa Harlech disrupts the natural systems to some degree. The area is a popular site for **tourism**, being part of Snowdonia National Park. Morfa Harlech has some of Britain's few sandy beaches, and despite the cold, wet and windy climate it is popular with holiday makers. Several large caravan parks and areas of mobile homes have been established at Morfa Harlech, sometimes very close to the foredunes. The dune area is used for many types of public recreation, and a large golf course covers much of the dune area near Harlech town. In an effort to protect the dunes from excessive trampling, fences have been built to restrict people's movement to narrow corridors, and motor vehicles and dune buggies have been banned from the entire dune area.

**2.57** Areas of mobile homes have been established to accommodate holiday makers on the sands of Morfa Harlech.

## Question Bank 2E

1. *Locate Morfa Harlech by giving (a) its absolute location, and (b) its situation relative to other places.*
2. *Where does the sand come from to form the sandy peninsula of Morfa Harlech?*
3. *What is isostasy?*
4. *How has isostasy affected Morfa Harlech?*
5. *What role has vegetation played in the formation of Morfa Harlech?*
6. *Figure 2.54 shows a topographic map of Morfa Harlech produced in 1995 at a scale of 1:50,000. With reference to the map, answer the following questions:*
   a. *Express the scale of this map as a statement.*
   b. *Draw a sketch map showing the main features of the area shown in the map extract. On your sketch map, draw a line around the approximate limits of Morfa Harlech peninsula.*
   c. *Calculate the area of each grid square on the topographic map extract.*
   d. *Use this information to estimate the area of Morfa Harlech peninsula.*
   e. *List the evidence shown on the map of human impact in the area.*
   f. *Harlech Castle is located at grid reference 581313, marked with the symbol of a double square (⧈). It was built by King Edward I and completed in about 1283. When it was built, it was situated on a cliff on the coastline. Using this information, (i) measure the distance of Harlech Castle from the coast today, and (ii) calculate the rate of coastal advance at Morfa Harlech.*

g. *Draw a cross-section along northing 32 from the coastline to easting 62. Label the cross-section with any significant physical and human features.*

h. *Calculate the average gradient of three sections of the cross-section: (i) from the coast to the B4573 road, (ii) from the B4573 road to the building in Merthyr farm, and (iii) from the building on Merthyr farm to the crest of the hill at 614320.*

7. *Using the topographic map in figure 2.54, estimate the grid reference from which the photographs in figures 2.51, 2.52 and 2.53 were taken, and state the direction in which the photographer was standing.*

8. *Figure 2.55 shows a topographic map of Morfa Harlech produced in 1840. With reference to the map, answer the following questions:*

   a. *Express the scale of this map as a ratio.*

   b. *Harlech Castle is marked with the rough symbol of a double square (⧈). Using this information, (i) measure the distance of Harlech Castle from the coast in 1840, and (ii) using your answer to question 6f(ii) say which period showed the most rapid average annual coastal advance - 1283 to 1840 or 1840 to 1995.*

9. *Using the maps in figures 2.54 and 2.55, write two pages to describe the changes between 1840 and 1995 in the area's (i) physical landforms and (ii) human use of the land.*

# Sand dune development

## Coastal sand dunes

Coastal **sand dunes** are ridges of sand deposited by the wind, which lie on the inland (and leeward) side of beaches. Like offshore bars, they represent a **store of sediment** that is available to replenish the beach during erosional sequences. In reality, they are a capping on top of wave-built beaches.

Three **conditions** are required for sand dunes to form. First, moderate to strong onshore **winds** are required. Second, there must be a **supply** of fine to medium beach sand, and third, **vegetation** is needed to trap and stabilise the sand. In some cases dunes extend several kilometres inland and to heights of 100 metres or more.

The large dune nearest the sea is often called a **foredune**, while the dune furthest inland is often called the **hindune**. The **incipient foredune** is a small dune forming immediately behind the swash limit. Plants colonise the incipient foredune and stabilise the shifting sands. Because they are the first plants to grow on any particular dune, the first species to grow on a dune is called the primary stabilising species. These plants must be very hardy, being **salt tolerant** (**halophytic**), having extensive **root systems** (often with **rhizomes**, or underground nodes that send out new shoots) to bind the sand, and the ability to **reduce moisture loss** in the dry, exposed environment of the dune. Typical examples are marram grass (native to Europe and introduced into many countries), American dunegrass (in North America, Asia and Russia), and spinifex (in Australia). Over time, more advanced species replace the salt-tolerant grasses and become established on the dunes, stabilising the dune and forming soil from the combination of decaying leaves and sand.

**2.58** American dunegrass stabilises these dunes on the east coast of the Kamchatka Peninsula, Russia.

While the foredune remains **stable**, no beach sand will move further inland. However, on beaches which receive some high waves and strong onshore winds, waves occasionally erode and cut away the foredune. This leads to breaches in the sand dune, allowing sand from both the foredune and the beach to blow inland. These breaches are called **blowouts**. If the onshore winds move the blowout inland beyond the hindune, it is called a **parabolic dune** because of its U shape. The curve of the U points in the direction of movement. On coastlines with strong winds and high waves, a series of parabolic dunes may join together into a sheet of unstable sand. Wind-blown sand will continue moving inland until stabilised, first by vegetation and later by soil-forming processes.

Coastal sand dunes form behind beaches that are stable or growing. If a beach continues to build out

2.59 A stabilised dune with a range of vegetation species at Punta del Este, Uruguay.

2.60 A large dune blowout on the southern coast of Coffin Bay National Park, South Australia.

towards the sea, then a series of **relict** (abandoned) **foredunes** are left behind. These provide geographers with evidence of former shorelines. They occur in lines and are called **beach ridges**.

## The role of vegetation on coastal dunes

A **vegetation community** is any collection of plants growing together and sharing certain distinctiveness. Some plants exist in one place and not in others, depending on other environmental factors such as soil, climate and their relationship to other plant communities and animals. Plant communities are dynamic, which means they are always changing. However, this change generally shows a definite trend in one direction.

All **progressive change** in which area gains more plants or more complex plants is termed **succession**. If an area is bare of vegetation, plants will begin to occupy it. The first species is known as the pioneer species. **Pioneer species** tend to be plants that are highly adaptable, have a short growth cycle, are small in size and are highly productive. Over time, the pioneer species modifies its environment so that the environment becomes less and less suitable for itself but more and more suitable for another species. As a result, the pioneer species is replaced by a **secondary species**, which in turn usually gives way to other species, and so on. This process leading to the development of a 'permanent' plant community is known as **seral progression**, and each stage is called a **sere**.

A vegetation succession on wind-blown sand is known as a **psammosere**. Psammoseres are typically found on coastal sand dunes or in sandy desert areas. The first stage in the development of any psammosere is **stabilisation** of the loose, wind-blown sand. As we saw earlier, the pioneer species that achieves this varies from country to country, but the characteristics of the different species are much the same as each other.

Once the wind-blown sand is stabilised, **salt compound**s that most plant species cannot tolerate, such as calcium chloride, carbonates and sulphates, must be removed. The pioneer species begins this process, enabling other species that are less tolerant of these chemicals to become established. These species in turn remove more of these chemicals, enabling still other species to become established. As these chemicals are removed, dead and/or decaying leaves are dropped by the plant species, adding **humus** to the sand. This is an important step in changing the sand into soil that can sustain higher order plant species. With each stage of the vegetation succession, moisture and temperature conditions are modified as a result of increased shading and reduced exposure.

Eventually, trees grow where once there was shifting sand. Each hindune was once the foredune of the beach and the dunes become younger and younger towards the shoreline. In other words, as a result of the process of vegetation succession on sand dunes, the **shoreline advances seawards** as time goes on, provided there are no interruptions such as intense storm activity. Psammoseres are

2.61 The vegetation on these sand dunes in Elmina, Ghana, has suffered from repeated trampling, especially by the teams of fishermen who haul in the nets containing their catch each day. As a result, the dune is heavily eroded and the beach is vulnerable to wave attack because there no reserve of sand available.

2.62 One way to protect coastal dunes from trampling is to construct elevated boardwalks over them, as seen here on Galveston Island, Texas, USA.

very **vulnerable** to disturbance. Strong winds and storm waves are common from time to time on most beaches, and this can erode a vegetation succession that has been forming for many decades.

The process of seral progression on coastal dunes is the result of an interaction between the plants and their habitat. As plants die, the products of their decay form humus, and the surface layers of the soil are altered physically and chemically. In this way, the habitat becomes more favourable to plant life, and plants that make greater demands are able to gain a footing. In the early stages of colonisation, the individual plants are scattered, but later plant communities become more closed until certain species become dominant, or several species may share dominance.


2.63 Revegetation of sand dunes is an excellent way to protect beaches from erosion. This dune restoration project in Galveston, USA, uses local grass species which are protected from trampling by fences that surround the new plantings.

Eventually the vegetation will reach a state of **dynamic equilibrium** where individual plants die and are replaced, but the overall **balance** of species remains constant. When this happens, we say that the plant community has reached its **climax**, or that we have the **climax community** for that area. The climax vegetation makes the most efficient use of all the resources of the habitat. At this stage, old plants are replaced by their own progeny and not by other species.

## CASE STUDY
## Wallagoot Beach, New South Wales

Wallagoot Beach is located on the far south coast of New South Wales, Australia, 460 kilometres south by road from Sydney and approximately 10 kilometres south of the beach resort town of Tathra. Its precise location is 36°49'S, 149°56'E. Wallagoot is a **barrier beach**, formed during the Holocene rise in sea levels following the last ice age. Figures 2.64 to 2.66 show three oblique aerial views of Wallagoot Beach and the areas immediately surrounding it.

Wallagoot Beach, and Bournda Beach at the southern end of the same beach, are part of the Bournda State Recreation Area, and are therefore given almost the same level of environmental protection as a national park. Figure 2.67 shows a 1:25,000 topographic map of Wallagoot Beach and its immediate vicinity. The areas shown in figures 2.64 to 2.66 all appear on this topographic map extract.

2.64 Wallagoot Beach, looking from the south-west. Wallagoot Lake appears in the left of this view, and the Tasman Sea is in the right background.

2.65 Wallagoot Lake, looking from the west, with Wallagoot Beach in the background.

2.66 Bondi Lake, looking from the east across Bournda Beach.

## Question Bank 2F

*Answer the following questions with reference to the Wallagoot 1:25,000 map extract in figure 2.67.*

1. *State the grid references for each of the following:*
   a. *the summit of Bournda Island*
   b. *the sea exit of Bournda Lagoon*
   c. *the ramp at 'Kooringal' on the northern shore of Wallagoot Lake*
   d. *the end of Bournda Road at Bournda Beach*
   e. *the eastern end of the walking track from Hobart Beach to Wallagoot Beach*

2. *Estimate the altitude of each of the following:*
   a. *the summit of Bournda Island*
   b. *the sea exit of Bournda Lagoon*
   c. *the small peak between Bondi Lake and Hobart Beach*
   d. *the end of Bournda Road at Bournda Beach*
   e. *the road junction at 620232*

3. *Identify the features at the following grid references:*
   a. *622207* b. *620225* c. *620210*
   d. *643241* e. *611237* f. *611252*
   g. *623223*

4. *State the straight line distance between:*
   a. *620210 and 620220*
   b. *The end of Bournda Road (619213) and the exit of Bournda Lagoon (621208)*
   c. *The northern and southern ends of Bondi Lake*
   d. *The summit of Bournda Island and the summit of Turingal Head*

5. *Draw a field sketch of the view you would see if you were standing at 619212 looking south-south-east.*

6. *Draw a cross section from the summit of the small hill at 605213 to the coastline at 628230.*

7. *Draw a sketch map of the area shown in the map extract, and label the following features: tombolo, barrier beach, Bournda Lagoon exit, Wallagoot lake exit, sand dune ridge, cliff.*

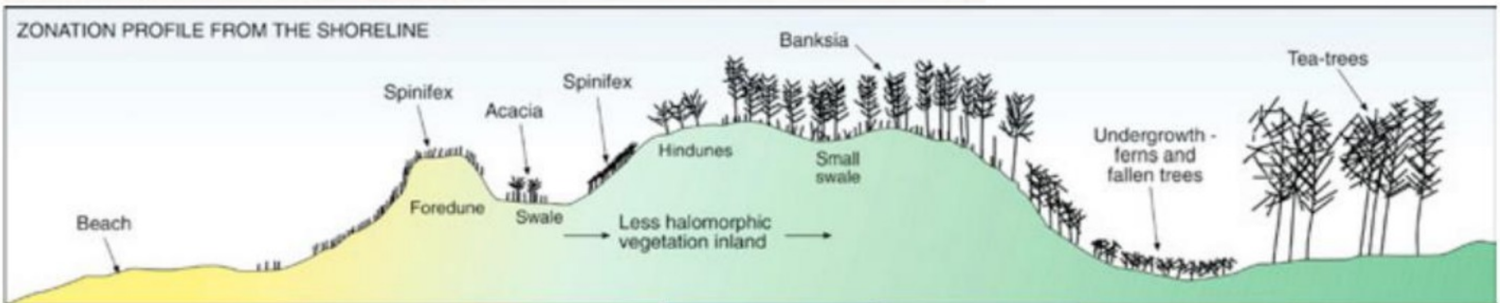
The dunes at the rear of Wallagoot Beach host a psammosere which is typical of the New South Wales coastline in areas that not been affected greatly by humans. However, like any natural system, the Wallagoot psammosere changes on a daily basis, reflecting recent weather, seasonal and wave conditions.

Figures 2.68 to 2.70 show the psammosere at Wallagoot Beach as observed during actual fieldwork. One of the key features of any vegetation succession is the interaction between the


2.67 Wallagoot 1:25 000 topographic map. See next page for the legend. Source: © Land and Property Information, Panorama Avenue, Bathurst. www.lpi.gov.au


vegetation and the soil in which each stage of the succession modifies the soil to prepare the way for the next stage in the vegetation succession. The information given in figures 2.68 to 2.70 emphasise this interaction, without which it is impossible to explain the processes operating to form and stabilise the dunes.

Sand dunes represent a **sediment reserve** that is eroded during times of heavy wave attack, such as storms. Wallagoot Beach has experienced such wave attack from time to time. For example, particularly heavy storms struck the area in 1978 leading to such severe erosion that the beach was eroded right back to the tea-tree zone, a distance of over 200 metres from the shoreline. The damage at that time is shown in figure 2.71.



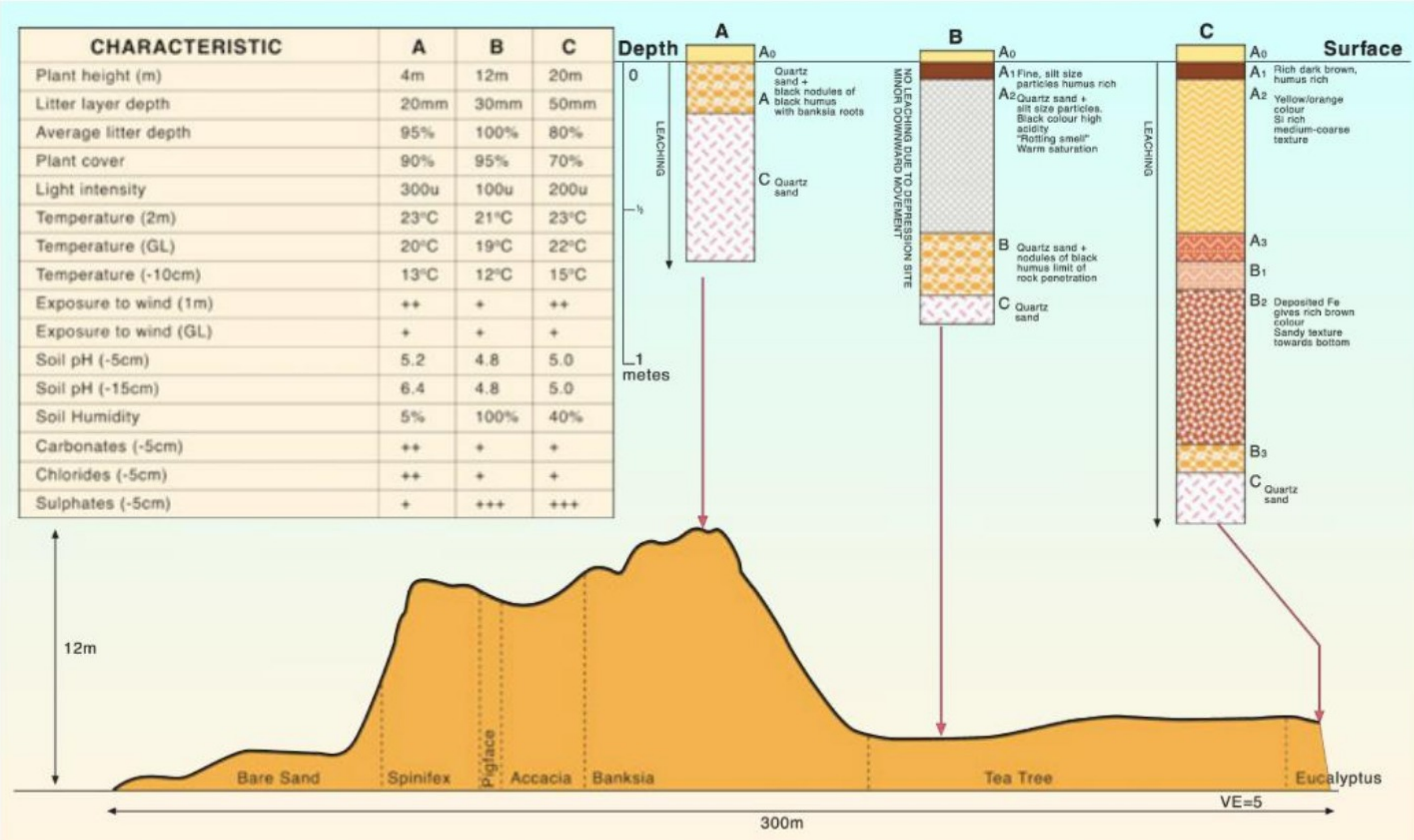

| Characteristic | Bare Sand | Spinifex | Acacia | Banksia | Tea Trees |
|---|---|---|---|---|---|
| Plant height (metres) | 0 | 0.2 to 0.3 | 0.4 to 1.5 | 4 to 6 | 10 to 12 |
| Litter layer depth (mm) | 0 | 0.01 | 1 | 20 | 30 |
| Average litter layer | - | 2% | 20% | 95% | 100% |
| Plant cover | - | patchy, 15% to 60% | 70% to 85% | 80% to 90% | 95% to 100% |
| Light intensity (1 metre above ground) | 1700 | 1000 | 500 | 300 | 100 |
| Temperature at 2 metres above ground (°C) | 21 | 28 | 28 | 23 | 21 |
| Temperature at ground level (°C) | 24 | 34 | 32 | 20 | 19 |
| Temperature at 10cm below the ground (°C) | 13 | 16 | 15 | 13 | 12 |
| Exposure to wind 1 metre above ground level | ++++ | +++++ | +++ | ++ | + |
| Exposure to wind at ground level | +++ | ++++ | + | + | + |
| Soil pH at 5cm below ground surface | 7.0 | 6.9 | 6.6 | 5.2 | 4.8 |
| Soil pH at 15cm below ground surface | 7.0 | 7.0 | 6.7 | 6.4 | 4.8 |
| Soil humidity | 60% | 0% | 0% | 10% | 100% |
| Carbonates in soil 5cm below ground level | +++++ | ++++ | ++ | + | + |
| Organic matter in soil 5cm below ground level | + | + | + | +++ | ++++ |

| KEY TO SYMBOLS | | | | | | |
|---|---|---|---|---|---|---|
| | Exposure to wind | +++++ Maximum exposure, no protection | ++++ Moderate exposure | +++ Average exposure | ++ Slight exposure | + Minimum exposure |
| | Carbonate concentration | +++++ Extreme effervescence | ++++ Strong effervescence | +++ Moderate effervescence | ++ Slight effervescence | + No effervescence with HCl |
| | Organic matter concentration | +++++ Extreme effervescence | ++++ Strong effervescence | +++ Moderate effervescence | ++ Slight effervescence | + No effervescence with $H_2O_2$ |

**2.68** Zonation profile and vegetation-soil interaction data for Wallagoot Beach.

| Zone plant | Metres from the sea to: Seaward edge | Landward edge | Photograph | Adaptation of plant to environment | Changes in environment from plant |
|---|---|---|---|---|---|
| Bare sand | 0 | 75 |  | | |
| Spinifex and other grasses | 75 | 97 |  | Halomorphic (salt-tolerant) ability to establish in almost waterless areas; uses runners and an extensive root system to survive in shifting sands, tightly curled leaf to minimise water loss. | Pioneer species stabilises the dune and removes salt from the sand; allows the first stage of soil development by adding humus. |
| Acacia species (wattle) | 97 | 120 |  | Sclerophyll (hard leaves to survive prolonged dry periods), leaves turn away from the wind to minimise transpiration, special small-sized halomorphic variety of acacia. | Stabilises the dune by providing continuous ground cover, breaking up strong winds at ground level; leaf litter adds further humus to the soil, increasing soil fertility. |
| Banksia species | 120 | 200 |  | Sclerophyllic (hard, brittle) leaves aid survival during dry periods, silver-white underlayer on the leaves helps to minimise water loss through transpiration, short thick woody trunk aids stability in strong winds. | Adds considerable humus to the soil, helping to convert sand into soil. |
| Leptospermum species (tea trees) | 200 | 1200 |  | Small leaves reduce water loss. Thick bark reduces moisture loss, provides protection during fires and enhances stability in strong winds. | Creates a cool environment at ground level due to thick leaf cover, inhibits ground cover due to lack of light under the thick canopy of leaves, deep roots add to soil development, thick leaf cover reduces wind exposure. |
| Eucalypt species | 1200 | |  | Sclerophyllic leaves help survival during long dry periods, evergreen leaves. Although this is the region's climax community, the seral progression here is interrupted by Wallagoot Lake. | Closed vegetation community, deep root system further develops soil. |

**2.69** The psammosere on the sand dunes at Wallagoot Beach, Australia.




| CHARACTERISTIC | A | B | C |
|---|---|---|---|
| Plant height (m) | 4m | 12m | 20m |
| Litter layer depth | 20mm | 30mm | 50mm |
| Average litter depth | 95% | 100% | 80% |
| Plant cover | 90% | 95% | 70% |
| Light intensity | 300u | 100u | 200u |
| Temperature (2m) | 23°C | 21°C | 23°C |
| Temperature (GL) | 20°C | 19°C | 22°C |
| Temperature (-10cm) | 13°C | 12°C | 15°C |
| Exposure to wind (1m) | ++ | + | ++ |
| Exposure to wind (GL) | + | + | + |
| Soil pH (-5cm) | 5.2 | 4.8 | 5.0 |
| Soil pH (-15cm) | 6.4 | 4.8 | 5.0 |
| Soil Humidity | 5% | 100% | 40% |
| Carbonates (-5cm) | ++ | + | + |
| Chlorides (-5cm) | ++ | + | + |
| Sulphates (-5cm) | + | +++ | +++ |

**2.70** Soils of the Wallagoot Beach natural system, Australia.

**2.71** A section of Wallagoot Beach showing damage from the major storms of 1978 which eroded the dunes right back to the tea-tree zone. This photo was taken two years after the storm and shows little evidence of recovery apart from some deposition of sand in the swash zone (shown at low tide in the foreground). Today, the dunes have recovered fully.

**2.72** Wallagoot Beach today, largely recovered from the heavy storm damage it sustained in the late 1970s.

## Question Bank 2G

1. *Explain why the first plants to colonise incipient sand dunes are halophytic.*

2. *It is said that the changes in vegetation over space (i.e. from the shoreline going inland) reflect the changes that have occurred over time. With reference to the vegetation succession at Wallagoot Beach, say whether you agree or disagree with this statement.*

3. *The raw data provided in figures 2.64 to 2.72 is sufficient to enable you to explain in detail the role of coastal processes the roles of wind and vegetation in forming the sand dunes at Wallagoot Beach. Write two to three pages to describe these processes fully.*

# Chapter 3 Managing coastal margins

3.1 Severe erosion on the coast of Accra, Ghana, has resulted in the loss of several buildings that collapsed into the Atlantic Ocean when the land on which they were built was undermined by wave action.

## Coastal erosion and flooding management strategies

### Management strategies

People are attracted to coasts, both to live and for recreation. **Population densities** in coastal areas are therefore often **high**, and this can place **stress** on coastal environments. Residential development, tourism, recreation, manufacturing and ports are among the functions that are attracted to coastal areas. Where these uses are incompatible in an area, **land-use conflict** is said to occur.

**Coastal erosion** has important implications for land use planning. In recent decades, people's preference to live near the sea has often meant that houses (and even high-rise home units) have been built on the foredune area of many beaches. Coastal dunes represent a reservoir of sand for the beach in times of wave attack. Houses and buildings built on dunes are therefore at risk during heavy seas. Every year, houses in various countries around the world are lost when heavy seas erode their dune foundations.

In some areas, and especially on retreating coasts, erosion is managed by building **sea walls** (**revetments**) at the back of the beach to protect

**3.2** Houses built in the dunes, Jamaica Beach, Texas, USA.

**3.3** Beach erosion on the coast of Surfers Paradise, on the Gold Coast of Queensland, Australia, has moved large volumes of sand from the beach to an underwater offshore bar. High rise developments have been protected by sea walls, but the same sea walls have amplified erosion of the beach.

structures behind. In general, this does help to stabilise the buildings on the dune, but it means that storm waves passing over the beach do not have their energy absorbed by the dunes at the back of the beach as would happen on a 'natural' beach. Rather, the waves **reflect** off walls that are built too far seaward in the active beach, and therefore impose a double dose of wave energy across the beach. In this way, walls built at the backs of beaches may lead to even more erosion of the beach, sometimes to the extent that corrective action is needed.

Newer sea walls overcome the problem of energy reflection by adopting structures based on technologies that **absorb wave energy**. One such action is **beach nourishment**, also known as **beach replenishment**, which involves supplying sand to

**3.4** This sea wall on Galle Face Beach, Colombo, Sri Lanka, has amplified erosion of the beach by reflecting wave energy. Consequently, very little sand remains on the beach despite attempts to control the movement of sediment with groynes.

**3.5** This artificial sea wall in Malmö, Sweden, has been built using large boulders that are designed to absorb wave energy rather than reflecting it back to sea. The boulders are too heavy to be removed by waves — even large waves during storms — and the gaps between the rocks trap wave energy.

**3.6** This energy-absorbing sea wall is made from small pieces of local coral from the atoll in the Maldives. The rocks are small enough to be carried away by large waves, so they have been packed into wire cages that become too heavy to be eroded.

**3.7** Concrete blocks, known as rip-rap, absorb the energy of incoming waves. This example of a rip-rap sea wall is on Betio Island, Kiribati.


**3.8** Beach nourishment on Broadbeach Beach, Queensland, Australia. This is a retreating coastline that experiences significant longshore drift, and erosion during storms is often severe. In this view, sand from elsewhere has been dumped, and is being moved in large trucks, some to replace sand lost by erosion, and some to form a foundation for a new sea wall.

beaches artificially to compensate for natural erosion.

Usually the beaches that are nourished are those with **high economic value**, such as for tourism. Beach nourishment may also be used on beaches that are losing sand due to longshore drift if the cost of beach nourishment is less than the perceived loss of income from tourism. Longshore drift also poses problems in inhabited areas where the mouth of streams and coastal inlets can become blocked by the shifting sand. In such places, the construction of **groynes** and **breakwaters** is often used to avoid siltation.

Most groynes are built of rocks, but in some places wooden groynes are erected. These are built at

**3.9** Groynes at Carthage on the Gulf of Tunis in Tunisia prevent erosion by longshore drift of the beaches used by tourists. Further protection is provided to this economically important beach by a stone sea wall on the beachfront in the foreground section of the beach.

**3.10** These wooden groynes at Criccieth, Wales, UK, were designed to trap sand and small boulders. An angled (bullnose) sea wall at the landward edge of the beach (background) is designed to protect the land without reflecting too much energy back to the beach. A roadway covers the entire dune zone.

**3.11** Large groynes and an offshore breakwater have been built to prevent siltation of Ballona Creek and Marina del Rey as they flow into the Pacific Ocean in Los Angeles, California, USA.

right-angles to the shoreline and prevent sediment being moved along the coast by longshore drift by trapping the sediments. This can prevent the loss of sediments to other sections of the coast, but the downside is that the other sections of coastline are deprived of replacement sediments. Therefore, groynes can often simply transfer the problem of loss of sediments from one location to another.

**Excessive use** of beaches by people can cause erosion and a loss of sand. This can occur when people **drive** on beaches, as happens in some countries. Erosion of sand dunes can be a significant problem when people **walk** across them. People's footsteps can **destabilise** the sand and destroy the vegetation that binds the sand together, leading to wind-blown erosion. This problem can be managed with the construction of fences to concentrate the human traffic, or the more expensive construction of elevated **walkways** or **boardwalks** over the top of the dune, provided people stay within the areas allotted.

3.12 A timber walkway with a fence has been built across the dune zone of this beach in Punta del Este, Uruguay, to protect the vegetation from trampling. As seen by the many footprints in the sand beside the walkway, many beach users have ignored the walkway, and this has resulted in erosion of the dune in the area around the boardwalk.

Because of the popularity of coastal areas as a place to live, waterfront views command premium prices on the property markets in many countries. One response to this by land developers has been to create **canal estates**, dredging networks of canals in low-lying swampy coastal areas to increase the proportion of properties with waterfront views. The properties created are often very expensive, and represent a major re-working of the natural

3.13 Raby Bay canal estate is a suburb of Brisbane, Australia, built by land reclamation. Construction of the canal estate destroyed seagrass meadows, mangroves and nesting sites for migratory wading birds. Groynes have been built to reduce the impact of erosion by longshore drift of the yellow sand that was brought in from elsewhere and dumped.

coastal environment. Because they are only just above sea level, such properties may be prone to **flooding**, especially if they are developed within reach of the tidal zone.

Many **poorer countries** lack the financial resources to manage retreating shorelines by means such as building sea walls, dune boardwalks, groynes or breakwaters, or by adding sand to eroded beaches through beach replenishment. Whereas richer societies prefer to respond to such environmental challenges by **modifying** their environment, most people in poorer societies have no option but to live **within the confines** of their environment, adapting to circumstances as best they can.

3.14 A low cost response to coastal erosion; an easily built and readily repairable sea wall made from used car tyres in Banjul, Gambia.

Nonetheless, some cheap, affordable, basic measures can be taken, usually through local initiatives rather than government action. **Low cost measures** to guard against coastal erosion include building sea walls using readily available local materials, or waste materials such as used car tyres.

In areas where **cliffs** are retreating due to wave attack, poorer societies have few options but to adapt to the situation, taking care not to build too close to the edge of a retreating cliff. In richer societies, engineering solutions are available, although being relatively expensive they are not widely used.

**3.15** This section of eroded cliff is located in Accra, Ghana, not far from the view shown in figure 3.1. Evidence of collapsed buildings and fallen rocks can be seen on the eroded cliff. The people who live in this area lack the financial resources to change their environment substantially, and they must adapt to the situation as best they can.

One way to stabilize the cliff line on a retreating coastline is to construct a **protective wall** at the base of the cliff. Alternatively, **large boulders** can be placed at the base of the cliff to absorb wave energy or, if the waves are gentler, shingles or sand could be placed at the base of the cliff. All these solutions require ongoing **maintenance**, which can be quite expensive in areas where wave attacks are strong or frequent.

Cliffs can also be stabilised by covering their surface with **concrete** or by a layer of **vegetation**, or a combination of the two. In either case, pipes need to be inserted at various points to remove excess water that would otherwise build up behind the covering layer and exert destructive pressures that could lead to sudden mass movement.

**3.16** A cliff near the sea (which is to the left of the roadway) near Phuket, Thailand, which has been stabilised with a layer of concrete and is having an additional surface layer of coconut shells containing vegetation applied. The truck is watering the new layer of vegetation.

**3.17** A steep section of this seaside cliff on Lamma Island, Hong Kong, has been stabilised with a surface layer of cement, interspersed with PVC pipes to drain the subsurface water. The rest of the cliff is stabilised by a dense cover of vegetation.

**3.18** Boulders have been applied to stabilise a steep section of eroded coastline north of Haast on the South Island of New Zealand.

Although it is preferable to prevent cliff retreat or collapse by implementing management strategies such as these before a hazard event occurs, this is not always possible, either for financial reasons or because the risk was under-estimated. In such cases, emergency repair works are sometimes necessary in an effort to stabilize a damaged shoreline or cliff. Typically, this involves dumping boulders in the affected area to absorb wave energy that might erode the vulnerable shoreline and protect the coastline that has been destabilised.

### Question Bank 3A

1. *Explain why building sea walls can be a negative as well as a positive management strategy.*
2. *List the coastal management strategies described in this section. For each management strategy, state a benefit and a shortcoming of the strategy.*
3. *Why are coastal management strategies likely to be different in richer societies compared with poorer societies?*

## CASE STUDY
## Management of Sydney's coasts

The coastal environment of Sydney, Australia, is under **intense pressures** from high population densities and competing demands for available resources that threaten the viability of remaining natural areas. Sydney's coasts are found within the metropolitan area of Australia's largest city, and this places huge pressures on them. The development and use of the fragile ecosystems has led to their gradual **degradation**.

In order to address these issues, a **Sydney Regional Coastal Management Strategy** has been developed. Before we examine this management strategy and its implementation, we should understand the physical environment of Sydney's coastline.

### Sydney's coastal environment

With a population of about 4.3 million people, Sydney is Australia's **largest city**. It is located on the east coast of Australia at a latitude of 34°S and a longitude of 151°E. Like Morfa Harlech (that we examined in the previous chapter), the evolution of Sydney's coastline has been affected by **changes in sea level** following the Pleistocene ice age.

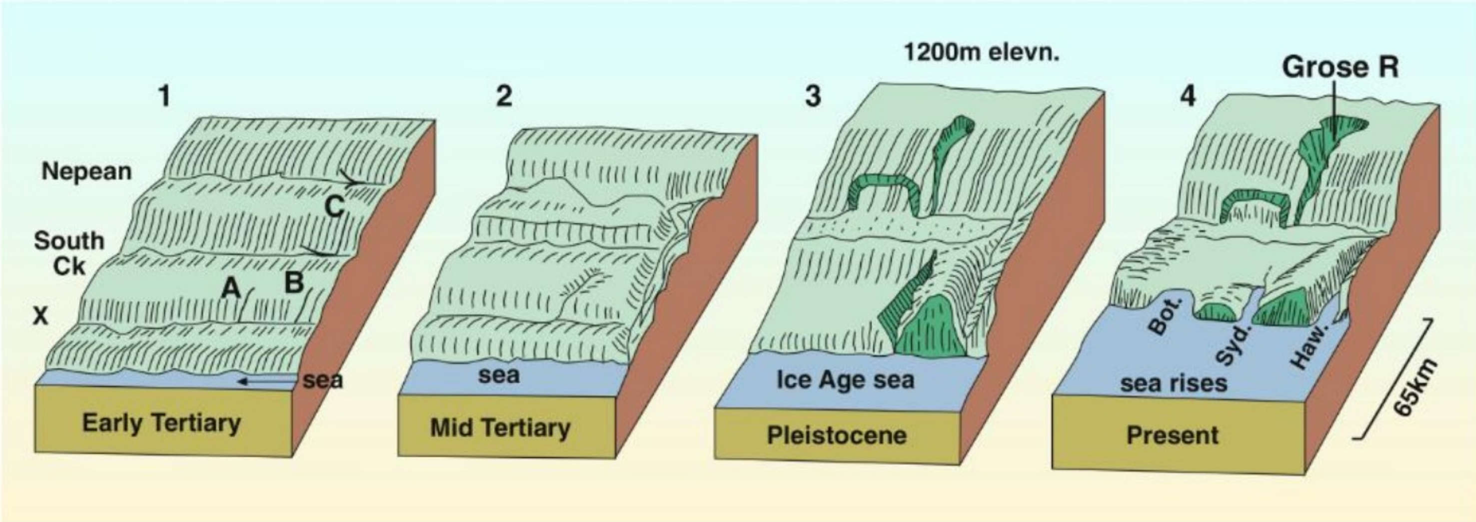
One of the first impressions gained from flying over Sydney is that Sydney's coastline comprises many inlets that are quite complex in shape providing excellent **shelter for shipping**. Indeed it was this, together with a reliable water supply, that led the British to settle at what is now the Central Business District of Sydney in 1788. From above, Sydney's harbours resemble the dendritic pattern of a river basin, and this gives us a good clue as to how they were formed.

**3.19** The dendritic shape of Sydney Harbour and Port Jackson is explained because they are rias (drowned river valleys), formed during the Holocene rise in sea level. Sydney's CBD is at the left of the photo, and the high-rise area across the Sydney Harbour Bridge to the right is North Sydney.

Before and during the last ice age (Pleistocene), when the sea level was much lower, Sydney's coastline was about 50 kilometres further to the east of its present location. At that time, the area where Sydney is now located resembled an elevated dissected sandstone plateau with several rivers running through deep valleys.

When the **Pleistocene** ice age ended about 11,500 years ago, the sea levels began to rise. The rise in sea levels continued for about 5,500 years during a period known as the **Holocene**. When the sea levels had finished rising about 6,000 years ago, the former river valleys in Sydney had been flooded. These drowned river valleys are known as **rias**.

About **65 million years ago**, before the Pleistocene ice age, most of the rivers in the Sydney region flowed towards the north (figure 3.20, block 1). At that time, the sea level was lower than the present level so the coastline lay further to the east. Thus there were **three northward flowing rivers** — the Nepean River which still flows today at the foot of




3.20 Simplified block diagrams showing the evolution of Sydney's coastline, looking from the east towards the west. Block 1 shows the early Tertiary period, about 65 million years ago. Block 2 shows the mid Tertiary period, about 40 million years ago. Block 3 shows the Pleistocene, about 12,000 years ago. Block 4 shows the present day. Botany Bay is labelled 'Bot.', Sydney Harbour is labelled 'Syd.', and the Hawkesbury River is labelled 'Haw.'. The Sydney metropolitan area covers the area from Botany Bay in the south to the Hawkesbury River in the north, extending from the coastline in the east to the foot of the Blue Mountains escarpment in the west.

the Blue Mountains to the west of Sydney, South Creek which still flows today into Narrabeen Lagoon, and a third river which can be called River X which flowed approximately where today's coastline lies. Two small tributaries to River X (labelled A and B in figure 3.20) and another small tributary into South Creek (labelled C) cut small valleys into the hills separating the northward flowing rivers.

As time went on, the landscape became eroded and the hills between the northward flowing streams were lowered. This enabled the Nepean River to meander across its flat floodplain and some of the small eastward flowing tributaries (B and C in figure 3.20) to cut through the hills and **capture** the waters of the Nepean River (figure 3.20, block 2). It is thought that this happened about **40 million years ago**. Soon after this time, the land to the east of River X **sank** down beneath sea level, either because of folding or because of a fault line in the rocks which ran along the course of River X. This enabled the sea to **advance inland** as far as the course of the old River X, which is the present coastline.

About **one or two million years ago**, there was a period of **orographic uplift** along the eastern edge of Australia. To the west of Sydney, this had the effect of raising the Blue Mountains along a fault line which ran approximately along the course of the Nepean River. Soon afterwards, the **Pleistocene ice age began**, lowering sea levels around the world including along the Sydney coast. This had the effect of **rejuvenating** the valleys of the Nepean River and Stream A (the Parramatta River), creating deep gorges (figure 3.20, block 3).

With the **Holocene** rise in sea level which occurred from 11,500 years ago to 6,000 years ago, the landscape was **flooded**, raising sea levels to the high levels of 70 million years ago once again, and forming the distinctive **rias** (drowned river valleys) of Sydney's coastline (figure 3.20, block 4). The 100 metre deep Parramatta River gorge formed Port Jackson and Sydney Harbour (labelled 'Syd' in figure 3.20), while the 300 metre deep gorge at the mouth of the Nepean River became the Hawkesbury River (labelled 'Haw' in figure 3.20). Thus, Sydney today has a network of **coastal inlets** which twist and turn like meandering river valleys, and these provide excellent shelter for shipping and thousands of small recreational boats. **Botany Bay** was an exception to this pattern. Unlike the other inlets, Botany Bay is more rounded in shape. There was no deep river gorge at Botany Bay, but rather a flat plain which warped gently and subsided, forming a saucer shape.

As a result of the Holocene rise in sea level, Sydney's coastline developed a pattern of alternating **headlands** and **bayhead beaches**. The ridges between the small old Pleistocene tributary streams became headlands after the rise in sea level,

**3.21** An oblique aerial view of Sydney's northern beaches, looking towards the north-east. In the foreground is Narrabeen Lagoon. Note the pattern of alternating cliffs and bayhead beaches.

**3.22** Avalon Beach in Sydney's north is typical of Sydney's beaches. It is a bayhead beach with well developed dunes stretching between two steep sandstone headlands with rock platforms at their bases. Note the rocks at the base of the cliff that have fallen as the cliff has been undercut by wave action. Note also the crescent-shaped cusps that are just visible at the far end of the shoreline (wave-sediment interface) and the fence to protect the dune vegetation, which in this case is spinifex, the pioneer species.

while the small river valleys between them were drowned to form **bays** and **inlets**. As the waves approached these bays, the energy was dispersed enabling the sandy deposits which were brought by the rising seas to be deposited in the heads of the bays.

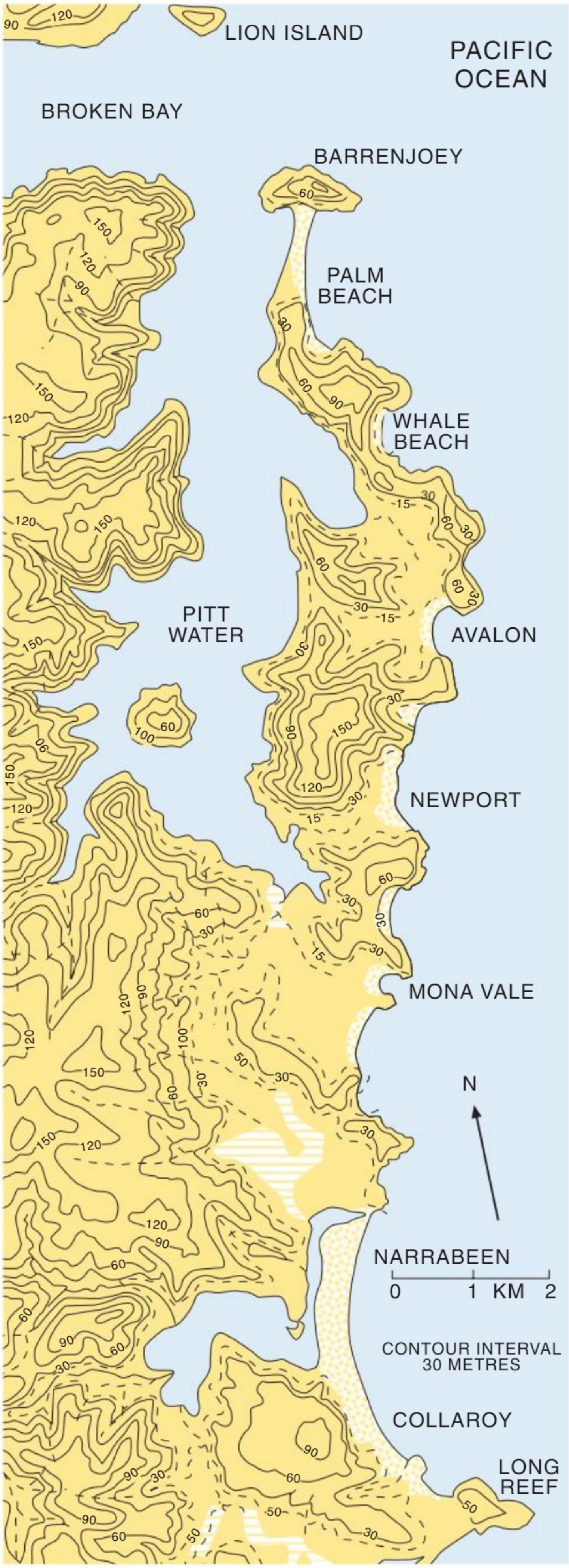
Both the headlands and the bayhead beaches have developed distinctive shapes in Sydney. The headlands usually have very steep (almost vertical) faces with a rock platform at their base. The reason for this is that the main type of rock in Sydney is **sandstone** which has been deposited in horizontal layers. When the wave energy is concentrated on to these headlands, the underlying layers of rock are **undercut**, undermining the layers above which collapse down into the sea.

The beaches between the headlands are usually **crescent-shaped**, following the shape of the waves which deposit the sand. Because Sydney is an urban area, the **dune areas** at the back of the beaches have often been built upon, a dangerous practice because the dunes are the 'emergency erosion protection' of the beaches during storms, and buildings on the dunes are vulnerable to wave attack and undermining. However, some of Sydney's beaches have dune areas which have been left, as far as possible, in a natural state.

The precise shape of beaches in Sydney varies according to the prevailing weather conditions. Using the model in figure 2.11, we can conclude that the beach in figure 3.22 has been building up during quite a long depositional phase. This is because the cusps indicate that the beach is at stage 2 of the depositional sequence. **Cusps** are the horn-shaped features which are formed at right-angles to the shoreline at fairly regular intervals along many beaches.

In some places along Sydney's coastline, the sequence of alternating headlands and bayhead beaches with rias is interrupted. This can be seen in figure 3.24, which shows a map of Sydney's northern beaches. At the southern end of this map, a peninsula named **Long Reef** can be seen. Long Reef is quite different in shape to all of Sydney's

**3.23** A typical section of sandstone cliffs, facing east to the Pacific Ocean at North Head. Note the build up of rocks at the base of the cliff that have fallen as a result of undercutting by wave action.




3.24 Map of Sydney's northern coastline.

3.25 An oblique aerial view of Long Reef tombolo, with its extensive rock platform. Narrabeen Lagoon is in the background.

other headlands. Rather than having a vertical face towards the sea, Long Reef slopes down to the sea much more gently. The reason is that Long Reef formed in a different way to Sydney's other headlands. When the sea level rose 6,000 years ago, Long Reef was an island. The waves which approached this island **refracted** right around it and crashed into themselves between the island and the mainland. As they did so, they dropped the sand they were carrying, forming a **spit** between the mainland and the island. Over time, this spit grew and joined the island to the mainland, forming a **tombolo**. The neck of the tombolo is today used as a golf course.

**Narrabeen** Beach, to the north of Long Reef, is different to most of Sydney's other beaches in that it comprises a **barrier**, separating a lagoon from the

3.26 Narrabeen Lagoon was formed during the Holocene when rising sea levels pushed sediments to form the baymouth barrier of Narrabeen Beach. Note the three cuspate spits in Narrabeen Lagoon.

3.27 Dee Why Lagoon was formed in a similar way to Narrabeen Lagoon, part of which is shown in the upper background. Dee Why Lagoon is located south of Narrabeen and just south of Long Reef, and like Narrabeen Lagoon, has a cuspate spit. The golf course covering the sand spit that joined Long Reef to the mainland to form a tombolo is seen in the right of the photo.

sea. When the sea level rose at the end of the Pleistocene, the area that is now Narrabeen Lagoon was an open bay. However, the rising sea brought a large supply of sediment, and this formed a barrier across the mouth of the open bay when the force of the incoming waves was matched by the force of the water trying to escape from the feeder streams into the bay/lagoon. At the time, the prevailing angle of wave attack was from the south-east, so it is thought that there was longshore drift towards the north. This accounts for the 'pushing' of the exit of the lagoon right up to the northern end of Narrabeen, against the rocky headland. Because Narrabeen Beach has blocked the entrance to a bay, it is known as a **bay mouth barrier**.

Three small streams flow into Narrabeen Lagoon. The stream from the south is South Creek, the

3.28 A cuspate spit in Narrabeen Lagoon.

remnant of one of the three ancient rivers in Sydney that were shown in figure 3.20. The other streams are Middle Creek (from the west) and Deep Creek (from the north). Each of these small streams has formed finger-like extensions of sediment into Narrabeen Lagoon, called cuspate spits. **Cuspate spits** form when the water at the edges of a stream slows down as it meets the still waters of a lake or lagoon into which it flows. Unless they have been disturbed, the youngest sediments in cuspate spits are found at the tips of the spit, with the sediments becoming older as one moves back towards the mainland.

In figure 3.24, a zone of low lying land can be seen joining Narrabeen Lagoon and Pittwater. This area of low land is believed to be the **remnant** of the valley of the ancient South Creek, which flowed northwards through Pittwater. At the northern end of the peninsula where Sydney's northern beaches are located, a sandy strip called Palm Beach joins a rocky peninsula called **Barrenjoey** to the mainland. Although Barrenjoey resembles the tombolo at Long Reef, its formation was much more like the bay mouth barrier at Narrabeen.

3.29 Barrenjoey tombolo, formed when the baymouth barrier of Palm Beach joined the island to the mainland during the Holocene rise in sea levels. In the background is the ria of Broken Bay and the mouth of the Hawkesbury River.

Like Long Reef, Barrenjoey was an offshore island at the end of the Holocene rise in sea level. As with Narrabeen, the prevailing angle of wave attack at Barrenjoey was from the south-east. The rising seas brought large quantities of sediment, and these sediments formed a **barrier** between the mainland and Barrenjoey (i.e. Palm Beach), creating a **tombolo**. The sediments were not able to stabilise north of Barrenjoey, however, because the Hawkesbury River gorge was much deeper than the shallow water south of Barrenjoey island. Furthermore, the pressure of water exiting from the Hawkesbury River eroded the sediments brought there by the waves, sweeping them offshore, making them available for bringing back to shore by later waves and deposition in the calmer waters south of Barrenjoey island.

### Question Bank 3B

1. *Summarise in words the evolution of Sydney's coasts as outlined in figure 3.20.*
2. *Make a precis map of figure 3.24. On your precis map, mark the (a) bayhead beaches, (b) headlands, (c) baymouth barriers, (d) a ria, (e) a tombolo, and (f) the probable ancient course of South Creek.*
3. *Explain the shape of Narrabeen Lagoon today.*

## Sydney's coastal management

The first edition of the **Sydney Regional Coastal Management Strategy** was developed in the late 1990s to provide (in the words of the document), a "strategic framework to focus and guide coastal planning and management practices into the next century". It was developed by the Sydney Coastal Council, a group established specifically to develop the Management Plan by all the local governments with jurisdiction over Sydney's coastal areas.

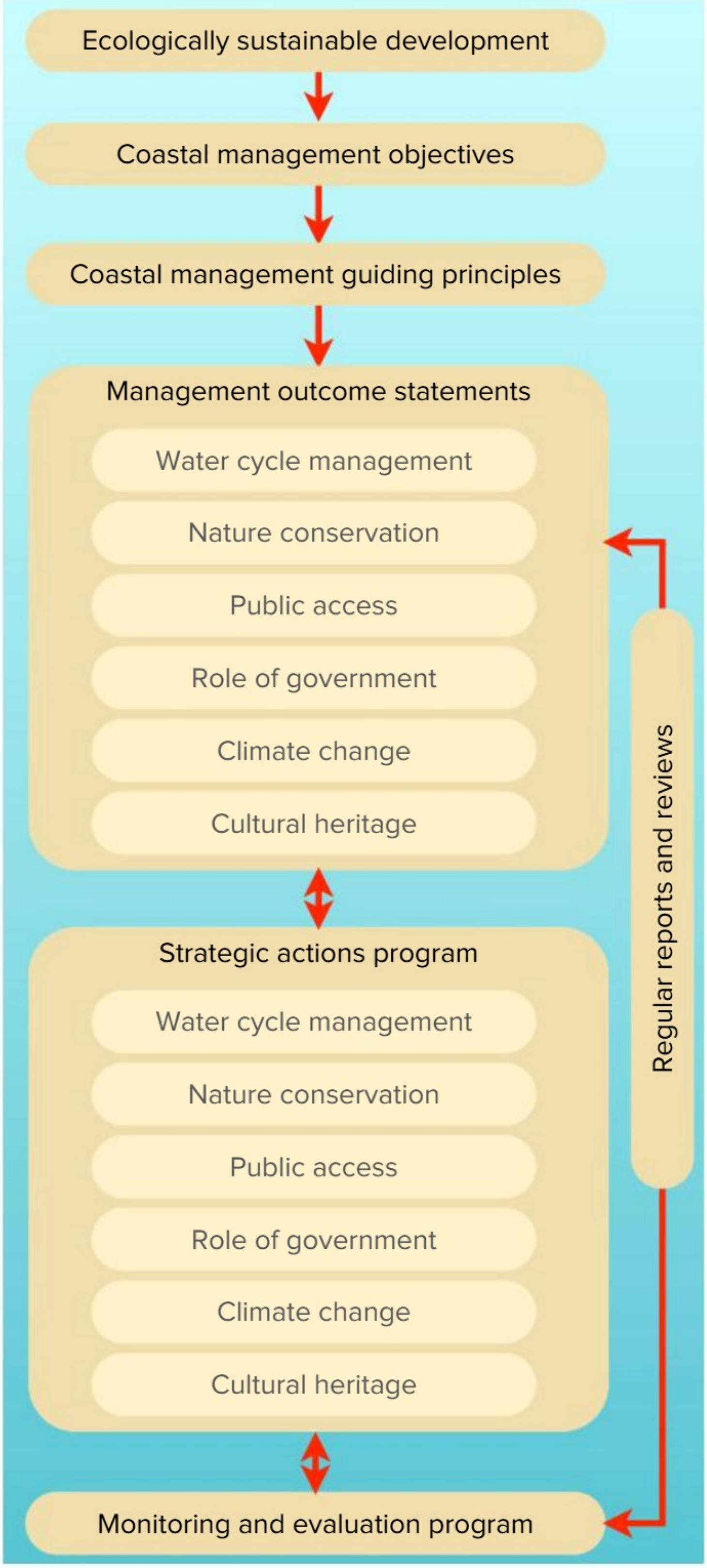
The **structure** of the Management Strategy is shown in figure 3.30. Based on a goal of achieving environmentally sustainable development, the management plan has **four objectives**:

- sustainable resource use
- resource conservation
- public participation
- knowledge and understanding.

These four objectives are fleshed out through a set of guiding principles which focus on **six outcomes** that are achieved through strategic actions:

- water cycle management
- nature conservation
- public access
- role of government
- climate change
- cultural heritage.

We will examine the management strategy by considering each of these outcomes in turn.




**3.30** The structure of the Sydney Regional Coastal Management Strategy. Source: Based on Sydney Coastal Council (1998), p.2

### Water cycle management

The first strategy of Sydney's coastal management plan is to achieve **sustainable management of the water cycle**. The objective is to achieve this by protecting the natural flows of water, enhancing water quality where possible, encouraging recycling where possible, replacing impermeable

3.31 The pipe beside this walkway at the southern end of Manly Beach is an old stormwater pipe, designed to collect runoff from nearby slopes and empty it into the ocean.

surfaces with semi-permeable surfaces, reducing water loss into pipes and controlling the discharge of sewage into the ocean.

In the 1800s, Sydney's **untreated sewage** was simply dumped through pipes into the ocean, often near beaches that were used for recreational purposes. The rationale was that this was a cheap way of disposing of sewage, and once it had been dumped in the ocean, it would be diluted and disseminated, cleansed by the combined action of salt water and the sun.

In the 1950s, dumping untreated sewage near beaches became so unpopular that governments were forced to look at alternatives. The solution that was implemented from the 1970s onwards was to construct **extended ocean outfalls**, which meant extending the outlet pipes to a distance of between two and four kilometres offshore and pumping the untreated sewage to that distance. It was decided not to treat the sewage because at that time, many companies were permitted to use the sewers to **discharge toxic wastes** cheaply, and these wastes would have killed the organisms required to break down and treat the sewage.

Although the offshore pipes produced visibly ugly brown plumes in the ocean when seen from the air, they were not generally visible from the shoreline. When onshore waves brought the effluent in to the shoreline, it was dispersed so that there were no visual or olfactory signals that the water contained untreated sewage. It was argued at the time that 90% of faecal coliform bacteria had died within one to seven hours of being pumped into ocean water during the daytime, and as sewage effluent took several hours to wash up on the shoreline, it was claimed there was no risk to public health.

Subsequent studies in the late 1980s showed that viruses can live in seawater for many months, and indeed can multiply and build up in concentration. In the 1990s, reports began to surface about high concentrations of organochlorines in fish caught off Sydney's coast. As a result of these reports, heavy **restrictions** were imposed on the dumping of toxic wastes into the sewers, and **sewage treatment plants** were built or expanded. Today, Sydney has 16 wastewater treatment plants that not only treat sewage before it is discharged into the ocean, but also produce biosolids that can be used in agriculture, horticulture and mining.

## Nature conservation

The second strategy of Sydney's coastal management plan is to ensure the **utilisation of plant and animal species is sustainable**, and the natural environment is protected, restored, rehabilitated and enhanced. The aim is to maintain:

- essential ecological processes (life-support systems);
- genetic, species and ecosystem diversity and productivity; and
- environmental and aesthetic qualities.

As it is located beside an urban area that was first settled by Europeans in 1788, Sydney's coastline had suffered from **degradation** of plant and animal habitats, and was losing some representative

3.32 Large areas of Sydney's coastline have been designated as public reserves to preserve the natural environment. This shows part of Sydney Harbour National Park, looking towards the Sydney CBD from North Head.

habitats. Insufficient attention had been paid to the consequences for plants and animals of allowing urban development adjacent to significant natural environments (such as animal breeding areas, wetlands and wildlife corridors), and hazard zones.

A major response to the need to protect natural environments has been the establishment of a network of **public reserves** and **national parks** along Sydney's coastline. The Royal National Park on the southern edge of Sydney is the world's second oldest national park (after Yellowstone in the United States), and the Sydney Harbour National Park preserves large areas of the natural coastal environment close to the heart of the Sydney urban area.

One of the biggest challenges in protecting Sydney's natural coastal environment arises because of the popularity of using the beaches for **recreation** — swimming and sunbathing in summer and surfing in winter. Getting to the shoreline involves crossing the **coastal dunes**, and these are fragile environments that are easily destroyed by trampling.

3.33 Coastal sand dunes at North Curl Curl Beach show evidence of erosion caused by trampling.

In the 1800s, large areas of Sydney's coastal dunes were destroyed when they were used for grazing cattle. Today, the challenge is to persuade people to get access to the beach using **designated walkways** that have been built on most of Sydney's high-use beaches. Some of the walkways include boardwalks in areas of heavy traffic, while other walkways attempt to confine traffic to a narrow zone using fences (often called 'people fences'). When beach users respect the walkways, the dunes can thrive and remain stable, but it takes only a little trampling outside the walkways to destabilize the dune, over-steepening the sand, killing the vegetation and making the dune vulnerable to wind erosion and wave attack.

3.34 This fenced walkway across the coastal dunes at South Curl Curl Beach has a walking surface of hard plastic to protect the dunes. The post at the left lists the prohibitions — no dogs, no litter, no smoking, no walking on the dunes, no horses, and no digging sand to open the entrance of the nearby lagoon.

3.35 Although this fenced walkway is designed to prevent people trampling the dunes, the bare sand with footprints shows that not all people stay within the boundaries of the walkway. Some of the plants on the dune are weeds that have established themselves opportunistically where the native vegetation has been destroyed by trampling.

Although native wildlife flourishes in areas of national parkland, special challenges arise for wildlife in areas visited by humans. One example of this is at Manly Beach where a community of **Eastern Water Dragons** live. These large lizards grow to about one metre in length and often sun themselves on coastal rocks. Some people have attempted to pick up water dragons and take them home as pets, so significant penalties have been imposed in an effort to protect the wildlife.


**3.36** A sign at Manly Beach to protect the Eastern Water Dragons in the area.

**3.37** Two Eastern Water Dragons at Manly.

## Public access

The third strategy of Sydney's coastal management plan is to **manage public access** and use of foreshore areas to ensure that fragile ecosystems and habitats are preserved, and to minimise risks to public safety. Compared with most parts of the world, Sydney's coastline is **freely available** to the public, with very few areas restricted by developments or private ownership. Such access has been guaranteed by the designation of large areas of the coast as national parks and public reserves.

Public access has been aided by a key outcome in the Sydney Regional Coastal Management Strategy, which was to establish a **coastal walkway system** that extends along the entire length of Sydney's coastline, including the estuarine areas. As part of this objective, **interpretative signage** is also being erected along the coastal walkway to explain issues such as cultural heritage, coastal conservation and biodiversity, coastal process issues and current management activities.

Public access has also been helped by expanding **public transport** and building **car parks** in environmentally safe areas. In extending public access, local governments have taken on a

**3.39** Open access to Sydney's coastline — fishing on the rock platform at Freshwater. Part of the coastal walkway can be seen.

**3.38** A panoramic view of Manly beach, showing heavy use during summer.

3.40 The coastal walkway at South Curl Curl.


3.42 Signs to encourage swimming in safe areas, Manly Beach.

3.41 The lookout point on the Fairfax Walk at North Head in the Sydney Harbour National Park provides walkers with views of coastal cliffs to the south as well as Sydney's CBD.

3.43 Access by car to many beaches in Sydney is regulated by local councils that charge parking fees. This example is at South Curl Curl.

3.44 A safety sign in Sydney Harbour National Park.

responsibility to ensure access is as safe as possible. This has involved maintaining the **quality** of walkways and access routes, and erecting clear **signage** warning of possible hazards and dangers.

## Role of government

Strategy number four of Sydney's coastal management plan acknowledges that much of the work of managing Sydney's coasts rests with **government authorities**. In Sydney, there are **three levels** of government — the Australian national government based in Canberra, the New South Wales state government based in Sydney, and sixteen local government councils with jurisdiction over coastal areas. The management plan provides a framework for all these governments to **share information** and work co-operatively towards achieving the objectives of the management strategy in a coherent manner.

While the national and state governments influence coastal management primarily through legislation and funding, local governments do more to provide infrastructure, to educate beach users about responsible use of coastal areas, and to encourage environmentally sustainable practices.

**3.45** Many local councils have built seaside swimming pools in the rock platforms at the end of beaches in Sydney. This example is at Avalon Beach. Note the rocks that have fallen to the bottom of the cliff in the background as a result of undercutting by wave action.

**3.46** A closer view of the same pool in figure 3.45 shows that a safety fence has been built to protect pool users from rocks falling from the shale cliff at its side.


**3.47** Recycling bins have been erected by the local council at South Curl Curl to encourage sustainable environmental practices by beach users.

## Climate change

The fifth strategy of Sydney's coastal management plan is to recognise, identify, monitor, plan for and mitigate the natural processes and hazards that are related to **climate change**. When the management plan was first published in 1998, climate change was not as widely recognized as a significant environmental force as it is today, so this statement represented quite an advanced perspective. The management strategy acknowledged several significant **shortcomings** that it aimed to address, specifically:

- a general lack of sufficient monitoring, analysis and information concerning the greenhouse effect and its potential impact on sea level and regional climatic variations;
- a lack of greenhouse-related policies, planning and development codes, and best practices;
- a lack of vulnerability (hazard) studies for the Sydney coastline; and
- ineffective and limited use of community awareness and education programs.

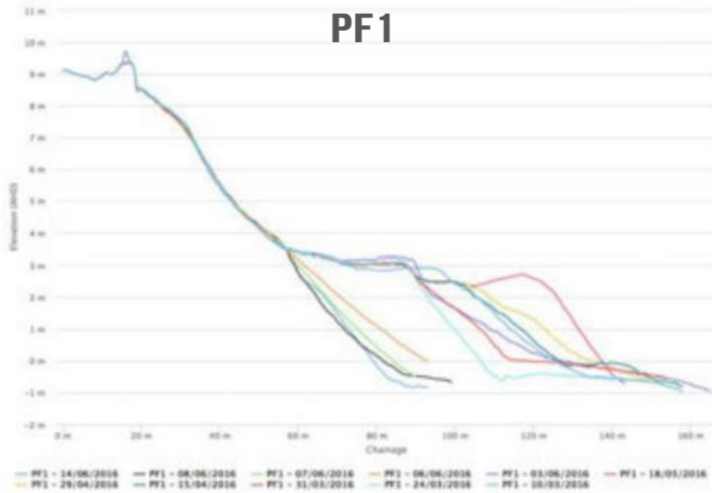
The main threat posed to Sydney's coastline by climate change is **erosion of beaches**, including the dunes, by wave action. As **sea levels rise** and the climate warms, the likelihood that **violent storms** with strong winds will form in temperate areas such as Sydney increases. As the frequency and strength of storms increases, the threat of erosive action by storm waves also increases, posing a significant risk that the erosional sequence shown in figure 2.11 will be activated all the way through to stage F.

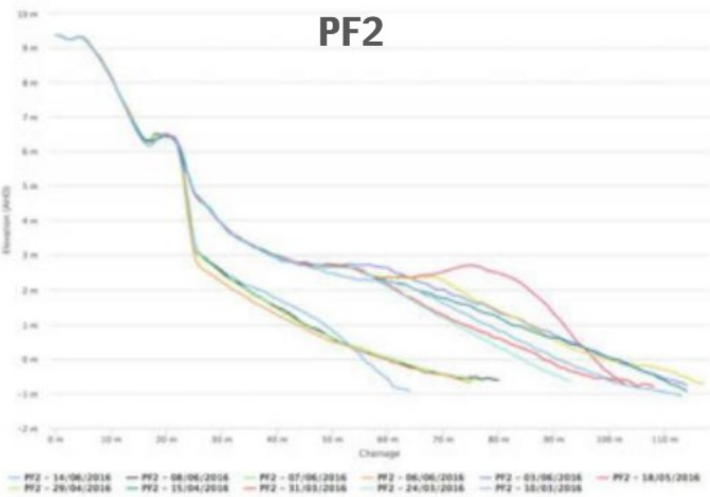
Even during normal weather cycles, the dunes on Sydney's beaches are **vulnerable to erosion** by wave action. This vulnerability is increased by human actions such as **trampling**, which is why access walkways and fences have been built across the dune zone on many of Sydney's beaches.

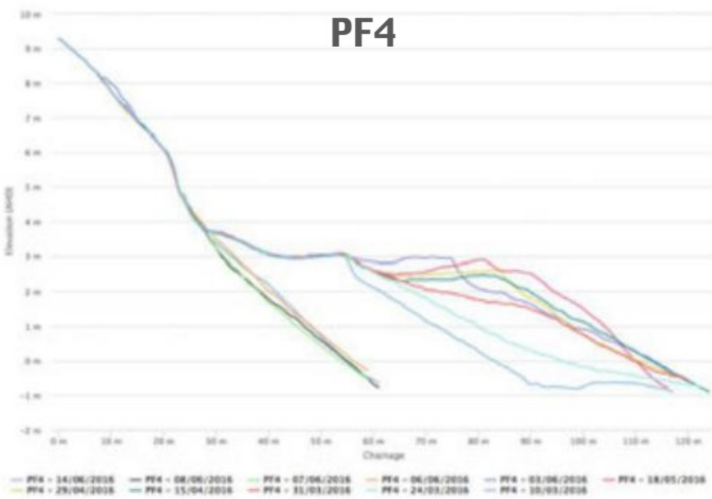
In early June 2016, severe erosion occurred along **Collaroy Beach** (which is at the southern end of Narrabeen) during a storm caused by an intense low pressure area. The erosion caused significant property damage, and many commentators suggested that this was an insight into the type of hazard event that will become more common on Sydney's coastline in future years as global warming occurs.

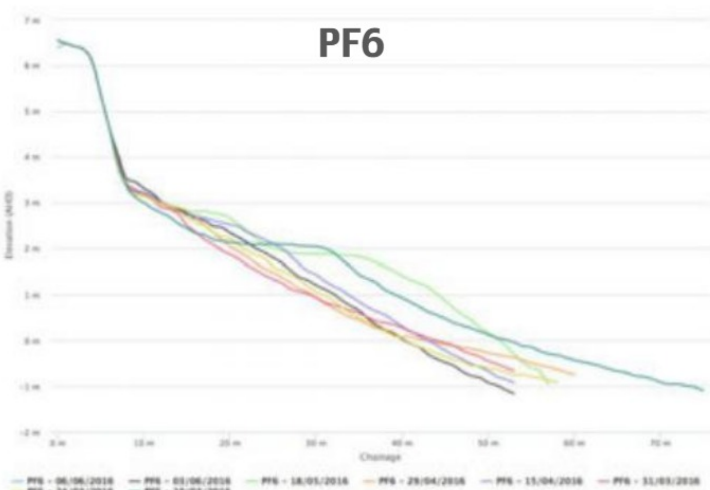

**3.48** Changes in the beach profile of Narrabeen and Collaroy Beaches from March to June 2016. The locations of the five profiles are shown on the aerial photograph to the left. These profiles show the pre-storm and post-storm beach profiles, including the impact of significant erosion that occurred during a major storm from 3rd to 6th June 2016. Dates are shown using the dd/mm/yyyy format.

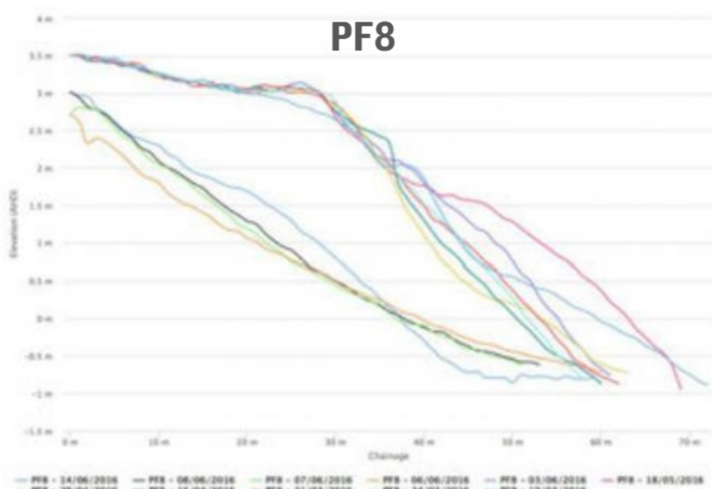
Source: Water Engineering Laboratory, School of Civil and Environmental Engineering, University of New South Wales, Australia. narrabeen.wrl.unsw.edu.au.



3.49 The dunes at North Curl Curl show significant erosion in areas where they are not protected by intact vegetation.

3.50 The potential effectiveness of vegetation in preventing dune erosion is shown by the intact dunes behind the 'people fence' at Newport Beach.


3.51 Severe storm erosion at Collaroy Beach in June 2016. In this view, the beach has been entirely removed and the hindune area is collapsing into the waves below. The stairs that used to lead down to the beach have been undercut and hang loosely in the air.

3.52 A week after the storm, heavy equipment has been brought in to clean up the damage of collapsed buildings and even a dislodged in-ground swimming pool.

During the storm, 450,000 cubic metres of sand were removed from the beach by the storm waves, which were up to 8 metres in height. As shown in figure 3.48, the storm **reduced the width** of the beach from 160 metres on 3rd June down to 90 metres on 6th June, moving the sand to an offshore underwater parallel bar.

During the storm, ten homes were undermined, leading to the partial collapse of several of them and loss of land. Several decks were destroyed and two in-ground swimming pools were undercut, leading to their collapse. In **response** to the erosion, 3,000 giant **sandbags** and **boulders** were brought in to protect the escarpment temporarily from further erosion. Within days, additional boulders were dumped to build an access ramp from the road to the newly lowered beach to allow repair crews to get access and clean up the damage.

3.53 A first response to the storm damage at Collaroy was to dump large boulders against the eroded beach to absorb wave energy and limit further erosion by storm waves.


**3.54** In order to repair damage from the storm at Collaroy, large boulders were dumped to stabilise the shoreline, after which an access ramp was built to the new, low beach level to give heavy equipment access for the clean-up operation. In this view, a deck that has collapsed is being lifted to be taken away and dumped.


**3.55** This sign at Collaroy Beach lists the ongoing actions taken by the local government in the area to mitigate the known erosion hazard. It is expected that climate change will continue to exacerbate this hazard.

## Cultural heritage

The sixth and final strategy of Sydney's coastal management plan is to protect, conserve and enhance items and areas of **cultural heritage** significance. This is to be achieved by recognising the rights and needs of **indigenous peoples**, together with improving public understanding of other significant areas of cultural heritage.

As a result of this strategy, national parks and public recreation facilities in coastal areas have increasing numbers of **signs** to inform visitors about the cultural heritage of the area. There is a common view that work still needs to be done to achieve a higher standard for this strategy.

**3.56** A section of the coastal walk between Curl Curl and Dee Why is known as Cobbers Way. Marked by an obelisk that was erected in 1917, it has the names of soldiers from the area who were killed in World War I etched into it. The soldiers camped at Curl Curl Beach before going overseas to fight in the war.

### QUESTION BANK 3C

1. *List the six strategies in the Sydney Regional Coastal Management Strategy in what you consider to be descending order of their importance. Justify your ranking.*

2. *Apart from personal decisions such as "shall I walk on the boardwalk through the dunes or not?", most of the decisions made to implement the Sydney Regional Coastal Management Strategy are made by government bureaucrats. Giving reasons, do you consider that is an effective decision-making framework?*

3. *Can you identify any important perspectives that are left out of the process of decision making in Sydney's coastal management?*

4. *Suggest ways that the management of Sydney's coasts could be improved.*

# Conflicting land-use pressures on coasts

Coasts are a **resource**. They are useful for humans in many ways, and this can lead to **conflict** when people's competing wants, needs and desires clash with others' priorities. Conflicts may arise between:

- human use of coastal areas and the natural environment; or
- one human land-use and a different, incompatible human land-use.

Most activities in a coastal environment have the potential to lead to conflict. For example, using power boats recreationally in a coastal area is incompatible with traditional people trying to make a living by fishing. Building a high rise hotel development is incompatible with preserving the natural environment in a public reserve. Dumping untreated sewage in the ocean is incompatible with either tourism or fishing. Land reclamation for residential development is incompatible with preserving a wetland area as a bird or fish breeding area.

3.57 The coast in Accra, Ghana. Among the land uses in this photo are fishing, residential (shanty) housing, hotels, restaurants, and government buildings. There is also significant erosion, blamed on construction of the Akosombo Dam on the Volta River in eastern Ghana. Completed in 1965 to produce hydro-electricity, the Akosombo Dam disrupted the flow of sediment from the Volta River to the coast. This means there is now less sand to replace the sediments that are eroded by wave

People's behaviour in coastal areas is **regulated** by laws. When laws are broken, those who break the laws are usually dealt with according to a well-defined set of penalties. Laws can be used to solve land-use conflicts, although in practice, those with **greater financial resources** often seem more likely to get their way.

Among the regulations that affect many coastal environments is the requirement for new proposed developments to pass an **EIS** (**Environmental Impact Statement**). Preparing an EIS means that the company or group applying for permission to built or develop a coastal environment is obliged to undertake a study that identifies all the likely impacts on the natural environment. If an EIS identifies a large range of significant impacts, then approval may not be given for the project, and this can be an effective mechanism to resolve potential land-use conflicts.


3.58 Another section of the coast in Accra, Ghana. Among the land uses in this photo are fishing, animal raising, rubbish dumping and burning, rubbish recycling, a City Government truck repair

## Question Bank 3D

1. *Identify the potential land-use conflicts in the section of coast shown in figure 3.57.*
2. *Identify the potential land-use conflicts in the section of coast shown in figure 3.58.*
3. *To what extent are commercial land uses in coastal areas incompatible with conservation measures?*

## CASE STUDY
## Land use pressure and conflict on the coasts of Sint Maarten

Sint Maarten is an island country in the **Caribbean Sea**, located at latitude 18°N, longitude 63°W. As shown on the world map at the front of this book, Sint Maarten is east of Puerto Rico and the Virgin islands, and north of Guadeloupe and Antigua.

**Sint Maarten** occupies the southern part of the island of **Saint Martin**, which is the smallest island in the world to be shared by two sovereign countries. The **area** of the entire island of Saint Martin is 87 square kilometres. The northern part, which has an area of 53 square kilometres, is known as **Saint-Martin**, is an overseas territory of France. The capital city of Saint-Martin is Marigot, with a population of 5,700 people. The southern part, with an area of 34 square kilometres, is Sint Maarten, and it is a former colony of the Netherlands. The capital city of Sint Maarten is Philipsburg, which has a population of 8,200 people. The total population of Saint Martin island is 78,000 people, of whom 41,000 live in Saint-Martin and 37,000 live in Sint Maarten. The population is growing through net immigration; the number of young people leaving to work and study abroad is more than offset by immigrants arriving to work in the tourism industry.


**3.59** The Caribbean island of Saint Martin is divided into two countries, Saint-Martin in the north and Sint Maarten in the south. Red areas represent urban centres, and orange lines represent roads.

**3.60** One of the border crossings between Sint Maarten (on the left) and Saint-Martin (on the right).

**3.61** An oblique aerial view of Sint Maarten showing its hilly terrain. The small bay in the foreground is Little Bay, and the large bay behind the narrow peninsula (Fort Amsterdam) is Great Bay. Sint Maarten's capital, Philipsburg, is at the left of the photo at the head of Great Bay. The cruise ship wharves are near the entrance to Great Bay.

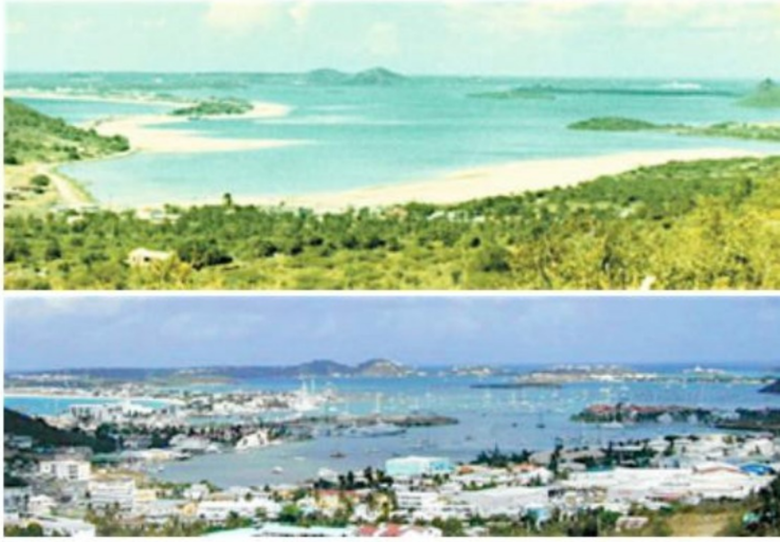
Sint Maarten has a warm, tropical climate, which combined with its sandy beaches and coral reefs, makes it attractive for tourists. The economy of Sint Maarten is overwhelmingly dependent on **tourism**, which provides 85% of all employment and about 65% of the GNP. Princess Juliana Airport is the main gateway for foreign tourists to come to Sint Maarten, although significant numbers of tourists also arrive by ship, especially the large cruise liners that dock in Philipsburg Harbour. Tourists arriving by air usually stay for a week or two to relax on the beaches and go diving, while day trippers from the cruise ships are attracted to duty-free shopping and gambling casinos in Philipsburg.


**3.62** The runway at Princess Juliana Airport in Sint Maarten borders Maho Beach, forcing airliners to make a very low approach across the beach to the delight of tourists.

**Tourist development** in Sint Maarten has mainly occurred in coastal areas near Princess Juliana Airport, where there are well-developed beaches with abundant accommodation, around Simpson Bay Lagoon (which provides ideal shelter for yachts and boats), and in the coastal strip around Philipsburg. Sint Maarten's coastline is a diverse mix of sandy beaches, bays, lagoons and rocky outcrops. As the coastal lowland strip reached capacity, development spread inland and up the steep slopes of the island's hills, requiring new roads to be carved into the hillsides that eroded the soil and released large quantities of sedimentation into the marine environment of the coasts.

The expansion of tourist facilities has had a significant **impact** on Sint Maarten's coastal environment. Many tourist developments are located close to, or even over, the water's edge. This poses a **threat** to the marine environment when pollutants are dumped into the water, either accidentally or through bad practice. On windy or wet days, sediments, cement, plastic bags and bottles, and construction site rubbish, can easily blow or wash into the sea, causing problems for coral reef organisms, seagrasses and mangroves. Increases in recreational boating also cause

**3.63** Tourism development around Simpson Bay Lagoon.



**3.64** The development of Simpsons Bay Lagoon, seen in the 1970s (top) and today (below), shows drastic changes to Sint Maarten's natural coastal environment.

pollution when oil and petrol leaks from boats and when ballast waters containing pollutants and bacteria are ejected.

**Sewage** is a major pollutant in Sint Maarten's coastal waters. Sewage is inadequately treated before being discharged into the sea, and it contains bacteria and substances that are harmful for marine organisms. Sewage from tourism is a particular problem in the highly developed, enclosed waters of Simpson Bay Lagoon and in Oyster Pond on the east coast where the water is in Sint Maarten but half the surrounding land (and source of sewage pollution) is in Saint-Martin.

Sint Maarten's **coastal vegetation** evolved to survive in a low energy coastal environments with saline water and sandy soils. Before large-scale coastal development for tourism and residential purposes, scrubby woodlands were found around

**Land and freshwater influence**
**MANGROVES**

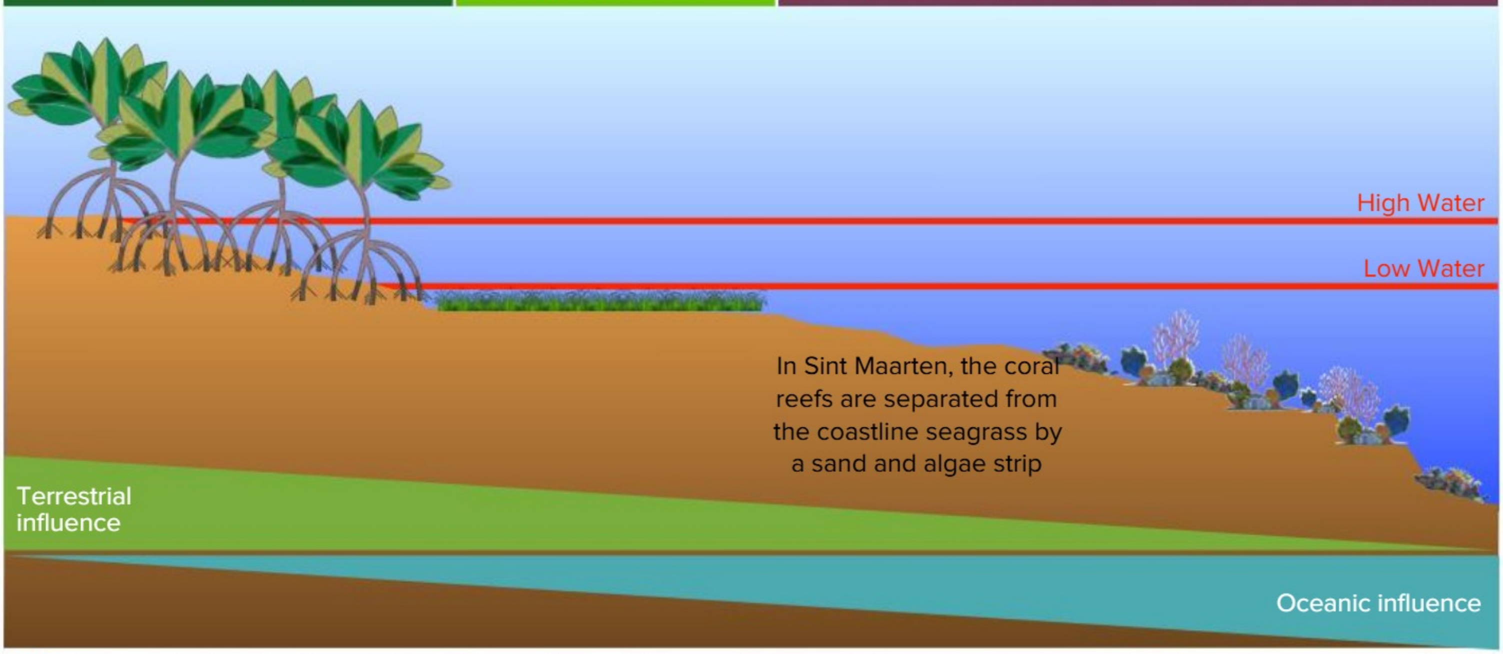
- Trap fine land sediments
- Consume and accumulate organic matter and nutrients
- Buffer changes in salinity
- Stabilise sediments
- Reduce wave action
- Export particles of organic matter

**Lagoon system**
**SEAGRASS BEDS**

- Stabilise and bind sediments
- Accumulate, consume and export organic matter and nutrients
- Poor at withstanding wave action

**Interface with the open sea**
**CORAL REEFS**

- Accrete calcium carbonate
- Accumulate organic matter and sediment
- Recycle nutrients and organic matter
- Consume suspended organic matter
- Produce sediment, e.g. parrotfish droppings
- Slow or divert water currents
- Protect from storm damage by reducing wave energy




**3.65** Sint Maarten's natural coastal vegetation. Most of Sint Maarten's coastal landscape has been developed to a large extent, and the mangrove and seagrass zones are now very rare. The large arrows at the foot of the diagram indicate the importance of the influences of the land and the ocean on the coastal landscape. Source: after DR MacRae.

the beaches and bays, while substantial mangrove and seagrass communities were found in the extensive flat coastal areas such as Simpson Bay Lagoon. Today, there are only a few small areas where the natural vegetation communities of mangroves and seagrass can still be found.

The **destruction** of most of Sint Maarten's natural vegetation has made Sint Maarten's coastline more vulnerable to erosion because the mangroves and seagrass played an important role in stabilising sand movement along the coast. The removal of sand to use for building has exacerbated the problem as removal has occurred at a faster rate than natural processes are capable of replacing.

Destruction of the **dunes** and beaches by **sand mining** has also hurt local wildlife, such as nesting turtles that use the dunes for breeding. This was a particular problem during construction of the Westin Beach Resort at Dawn Bay when heavy vehicles drove across the beach and dunes, endangering the plants and animals living there. The nesting turtles require low light and no disturbance to lay their eggs, and this is incompatible with large scale building, construction and coastal development.

**Invasive plant and animal species** have become a problem as agricultural and tourist developments have wiped out native plants. This has given opportunistic plants a chance to invade. Some invasive animal species, such as mongoose and raccoons, threaten native wildlife by feeding on eggs and eating small animals, including endangered reptiles and birds. Sint Maarten has a small population of about 70 feral Green Monkeys that were brought to the island as pets by slavers, transported with enslaved Africans to Sint Maarten in the 1700s. Although the number of monkeys has not reached invasive levels, they do sometimes harass dogs and people. None of the alien species has any natural predators in Sint Maarten.

The development of Sint Maarten's **rocky shores** for tourism leads to a different set of impacts. In some areas, rock has been mined and removed from the coastline to provide foundations for

3.66 A typical resort hotel in Sint Maarten shows the complete transformation in the natural coastal environment that occurs as tourism expands.

building hotel and resorts. The rocky shorelines provide essential protection from the impact of wave action, shielding softer sandy areas behind from erosion. Furthermore, rock platforms provide a habitat for marine organisms as well as habitats for some endangered sea birds such as the Least Tern, the Royal Tern and the Sooty Tern.

A significant land-use conflict is occurring at **Geneve Bay**, one of the last undeveloped bays in Sint Maarten. Located on the south-eastern coast of Sint Maarten, Geneve Bay is only accessible by hiking, as there are no roads in the area. The bayhead beach in Geneve Bay consists of black sand, and so is not as attractive for sunbathers as other beaches in Sint Maarten. The appeal of Geneve Bay for tourists focuses on surfing and hiking.

3.67 Tourist development at the southern end of Maho Beach shows an entire peninsula covered by infrastructure, with additional construction over the rocks to maximise use of space.

3.68 Geneve Bay, Sint Maarten.

In order to prevent resort developments in Geneve Bay and preserve the natural environment, conservation organisations such as the **Nature Foundation of Sint Maarten** have proposed declaring the area (along with several other non-coastal areas in Sint Maarten) a **protected area**, officially called a 'Land Park'.

Geneve Bay is a **significant natural environment** because it contains several species of endangered cacti, it is one of the few areas that still contains a substantial area of indigenous plants, and it is the last significant unbuilt area in Sint Maarten. Geneve Bay adjoins the existing Sint Maarten Marine Park (which is a voluntary protected area for marine life to breed). This is significant because any change to the land use of Geneve Bay, such as residential or tourist development (or even farming), would increase runoff, pollution and sedimentation, damaging the waters of the Marine Park and smothering nearby coral.

**Increased runoff** from the land usually contains pollutants such as oil from roads and fertilisers that kill marine organisms. The uninhabited offshore islands where sea birds nest, such as Guana Key, Cow & Calf, and Hen & Chicks, are especially vulnerable to disturbance. Geneve Bay is also believed to have historical value as a place where pirates used to land with contraband.

The area proposed for the Geneve Bay protected area covers 100 hectares, and is presently under the control of **several private owners**. These owners might understandably seek to profit from their land by selling it for residential or commercial development.


3.69 South-eastern Sint Maarten, showing the location of Geneve Bay. (Source: Based on Google Maps).

The Nature Foundation of Sint Maarten has proposed that **tourist developments** should be **prohibited** in Geneve Bay, and access should be limited to guided tours, walking trails, research and use of the beach. The Nature Foundation identifies the main **risks** to Geneve Bay as tourism development and invasive species that would come if the natural plant and animal communities become degraded.

Several **alternative land uses** have been informally proposed for Geneve Bay, some more seriously than others:

- Construction of a **resort hotel** with a casino;
- Development of the east-facing hillside for **farming** tropical fruit trees, or perhaps sugar;
- Establishment of a **dairy farm** or two to reduce Sint Maarten's dependence on imported foods;
- Re-establish one of Sint Maarten's traditional industries, which is **salt production** from evaporative ponds beside the sea;
- Building a **golf course**, which would involve replacing natural habitats with introduced plants species;
- Develop a source of sustainable energy by building a **wind farm** facing eastwards to the sea;
- Building an **exclusive residential** housing development for high-income earners;
- Construction by the government of **low cost, high rise housing blocks** to accommodate immigrants from nearby islands who can provide cheap labour in the tourism and hospitality industries; and
- The Nature Foundation's proposal to designate Geneve Bay as a **protected area**, prohibiting any development that would harm the natural environment of the coast or adjacent ocean waters.

Sint Maarten's **legal framework** offers little support for the Nature Foundation's proposal to designate Geneve Bay as a protected area, as there are currently no designated protected areas in Sint Maarten. However, as a result of **international**

Table 3.1

The proposal to designate Geneve Bay as a protected area; analysis of roles and desired outcomes for stakeholders

| Stakeholder | Viewpoint on designating Geneve Bay a protected area | Biggest concern about designating Geneve Bay a protected area | Likely reasons or evidence | Which solution from the list on the previous page would be preferred? |
|---|---|---|---|---|
| Nature Foundation President | | | | |
| Hilton Hotels Director | | | | |
| Geneve Bay land owner | | | | |
| Local commercial fisherman | | | | |
| Local bus driver | | | | |
| Local fruit tree farmer | | | | |
| Local unemployed woman | | | | |
| Visiting tourist from Germany | | | | |
| Lobbyist for the sustainable energy industry | | | | |

**agreements** that Sint Maarten has signed, the government is required to have legislation that allows for the establishment of Nature Parks. In 2003, the Sint Maarten Government adopted a Nature Conservation Ordinance that allows for the protection of flora and fauna, and establishing Geneve Bay as a protected area could fall under that law.

The final decision regarding Geneve Bay's land-uses will almost certainly involve the Sint Maarten **government** as well as other **stakeholders**, including the land owners, property developers, and potential purchasers of the land.

### Question Bank 3E

1. *Describe the impact of tourism on the coastal environment of Sint Maarten.*
2. *Explain why the destruction of Sint Maarten's native coastal vegetation harms the quality of the coastal environment.*
3. *Why is Geneve Bay described as a significant natural environment?*
4. *Using the matrix in table 3.1, analyse the likely perspectives of the coastal stakeholders listed on the question of designating Geneve Bay as a protected area.*
5. *Giving reasons, and taking into account the possible alternative land uses listed as bullets on the previous page, say whether or not you would support designating Geneve Bay as a protected area as proposed by the Nature Foundation of Sint Maarten.*

# Management of coral reefs and mangrove swamps

## Development of Coral Reefs

Although they are as hard as rock, **corals** are a type of **living organism**, built when organisms called polyps secrete calcium carbonate skeletons.

Although all coral reefs are found in the warm waters of the **tropics**, there are three different types with different shapes that reflect the different ways in which they were formed.


3.70 Types of coral reefs.

**Fringing reefs** form in areas where free-floating coral larvae attach themselves to the shallow, rocky seabed surrounding a tropical island. As a living organism, coral needs an abundant amount of sunlight, which is why fringing reefs grow best in shallow, clear water. Fringing reefs are the most common type of reef in the Caribbean Sea and parts of Hawaii and Micronesia.

Unlike fringing reefs, which may come right to the shoreline, **barrier reefs** form in a line roughly parallel to the shoreline but separated from it by a shallow lagoon. Barrier reefs often start to form as fringing reefs, but as the land sinks or the sea rises, the coral grows upwards to maintain growth within the shallow water than sunlight can penetrate. The Great Barrier Reef on the north-east coast of Australia is an example of a very large barrier reef, being about 2000 kilometres in length.

3.71 Fringing reef, Micronesia.

3.72 A fringing reef adjoins the land and encircles the island of Nauru in the Pacific Ocean.

3.73 Part of the shallow lagoon between the southern shoreline of Viti Levu, the largest island in Fiji, and its barrier reef (visible just above water level in the right background).

3.74 The barrier reef at Lauli'i on the southern edge of the main island of American Samoa is seen as a line of breaking waves that separates the shallow waters of the coastal lagoon from the dark blue deep ocean waters beyond.

The third type of reef is the **atoll**. Atolls begin forming as fringing reefs which become barrier reefs around an island as it sinks. The corals continue growing upwards on the outside of the island, and when all the land of the original island has disappeared below sea level, a circular ring of coral with some sediment in the middle is all that remains. This is the atoll, and it represents the final stage of a sinking island. Atolls are quite common in the South Pacific where old volcanic islands have sunk into the ocean. The largest atoll in the world, Kwajalein in the Marshall Islands, encircles an oval lagoon that is about 100 kilometres long.

3.75 Abemama is an atoll in the Gilbert Islands of Kiribati. It covers an area of 27 square kilometres and has a maximum altitude of 3 metres above sea level.

Most of the coral reefs found in the world today are of quite **recent origin** in geological terms, having formed since the end of the last ice age during the past 11,500 years. As the Pleistocene ice age ended and the glaciers and ice caps melted, the world's oceans rose. As the water level rose, the coral had to grow upwards to survive.

The **rate of growth** of a coral reef depends on many variables, including temperature, solar radiation, calcium carbonate saturation of the water, turbidity, sedimentation, salinity, acidity, nutrients, level of pollution — and the species of coral in the area. To give some idea of the differences in growth rates, the growth rate of Australia's Great Barrier Reef is said to vary between 0.8 millimetres per year to 80 millimetres per year.

Because of their beauty and their location in warm, tropical areas, coral reefs are significant **tourist attractions**. This gives reefs a **high economic value**, and the net worth of coral reefs is estimated at about US$30 billion each year. Expressed in another way, the United National Environment Program (UNEP) estimates the value of coral reefs to be somewhere between US$100,000 and US $600,000 per square kilometre per annum. Most of this value is generated from **nature-based tourism** such as scuba diving and snorkelling. On the other hand, the UNEP estimates that the annual cost of **protecting** coral reefs (mainly management costs of marine protected areas) is just US$775 per square kilometre.

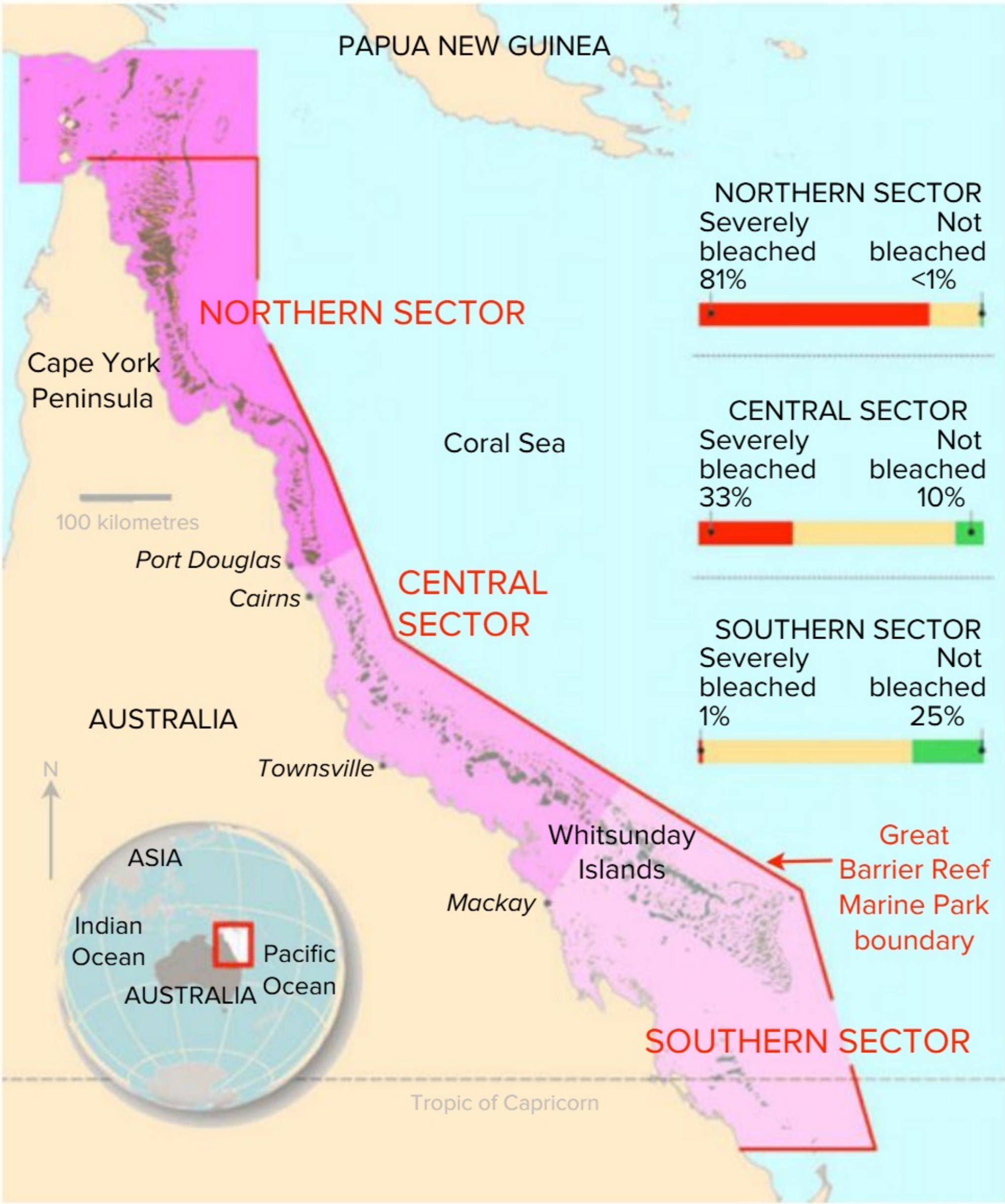
In addition to their value for tourism, coral reefs provide a variety of **benefits**, some of which are easier to measure than others. For example, reefs help **reduce beach erosion** by absorbing much of the energy of incoming waves. It has been estimated that each one square kilometre of coral reefs reduces coastal erosion in Sri Lanka by 2,000 cubic metres each year. Furthermore, coral reefs **help fishing** by providing breeding grounds. According to the World Resources Institute (WRI), properly managed coral reefs can yield an average of 15 tonnes of fish and other seafood per square kilometre each year, and coral reef fisheries in South-east Asia are estimated to yield US$2.4 billion annually.

## Question Bank 3F

1. *Describe the formation of the three types of coral reefs, and explain why these three types of reefs are really successive stages in a single process of reef formation.*
2. *What are the factors that affect the rate of growth of coral reefs?*
3. *What environmental benefits do coral reefs bring?*

## CASE STUDY
## Management of coral reefs on Australia's Great Barrier Reef

The **Great Barrier Reef** is a collection of 2,900 individual coral reefs off the east coast of Queensland on the north-eastern coastline of Australia. The Great Barrier Reef extends over 2,300 kilometres from Cape York Peninsula in the north to Fraser Island in the south, making it the **longest barrier reef** system in the world. The entire Great Barrier Reef has been designated as a **Marine Park** with an area of 348,000 square kilometres.




**3.76** Location of the Great Barrier Reef. The three bar graphs show the proportion of coral in each sector of the Great Barrier Reef Marine Park in 2016 that was severely bleached (red bars), moderately bleached (yellow bars) and not bleached (green bars).

With an ecosystem that has evolved over millions of years, the Great Barrier Reef is unique for its **biodiversity**. It contains over 1,500 species of fish, 360 species of hard coral, one-third of the world's soft coral species, 5,000 species of mollusc, 215 bird species, 30 species of marine mammals (including the endangered dugong), six of the world's seven endangered turtle species, and thousands of different types of sponges, worms and crustaceans.

There is great **variety** among individual reefs in the Great Barrier Reef system. There are two main classes of reef, **platform reefs** (also known as **patch reefs**) that result from radial growth, and **wall reefs** that result from elongated growth, usually in areas with strong currents. Many patch reefs begin as **fringing reefs** where growth is established on sub-tidal rocks (rocks that are always submerged) off the mainland coast or around some offshore islands.

The Great Barrier Reef is subjected to a number of **natural stresses**. The area is affected by **hurricanes** (tropical cyclones), and these generate large waves that damage the coral. The intense rain from hurricanes also brings large volumes of fresh water through rainfall and runoff, and this reduces the **salinity** level of the ocean, placing stress on the coral.

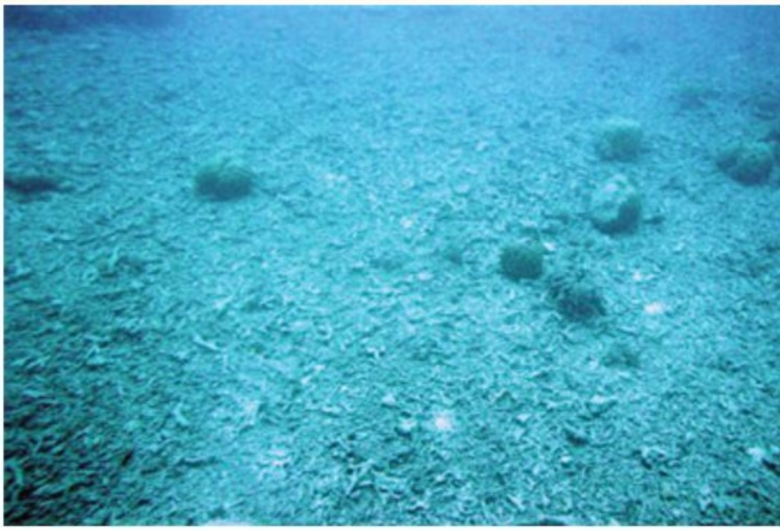
Another natural stressor is the **crown-of-thorns starfish**, a naturally occurring species that from time to time reaches plague proportions and consumes large quantities of coral. The numbers of the starfish only decline to a sustainable level when they have eaten so much coral that their food supply is exhausted. In the meantime, huge areas of the Great Barrier Reef are destroyed.

**3.77** The Great Barrier Reef has an extraordinarily diverse range of coral species, which provide a variety of habitats for fish and other marine species.

**3.78** Hoskyn Islands Reef near Gladstone is an example of a patch reef.

**3.79** Boult Reef is an example of a patch reef that has developed into an atoll.

**3.80** Vlassoff Reef near Cairns contains a cay, which is a low bank of sand that has collected in a coral depression by wave action.

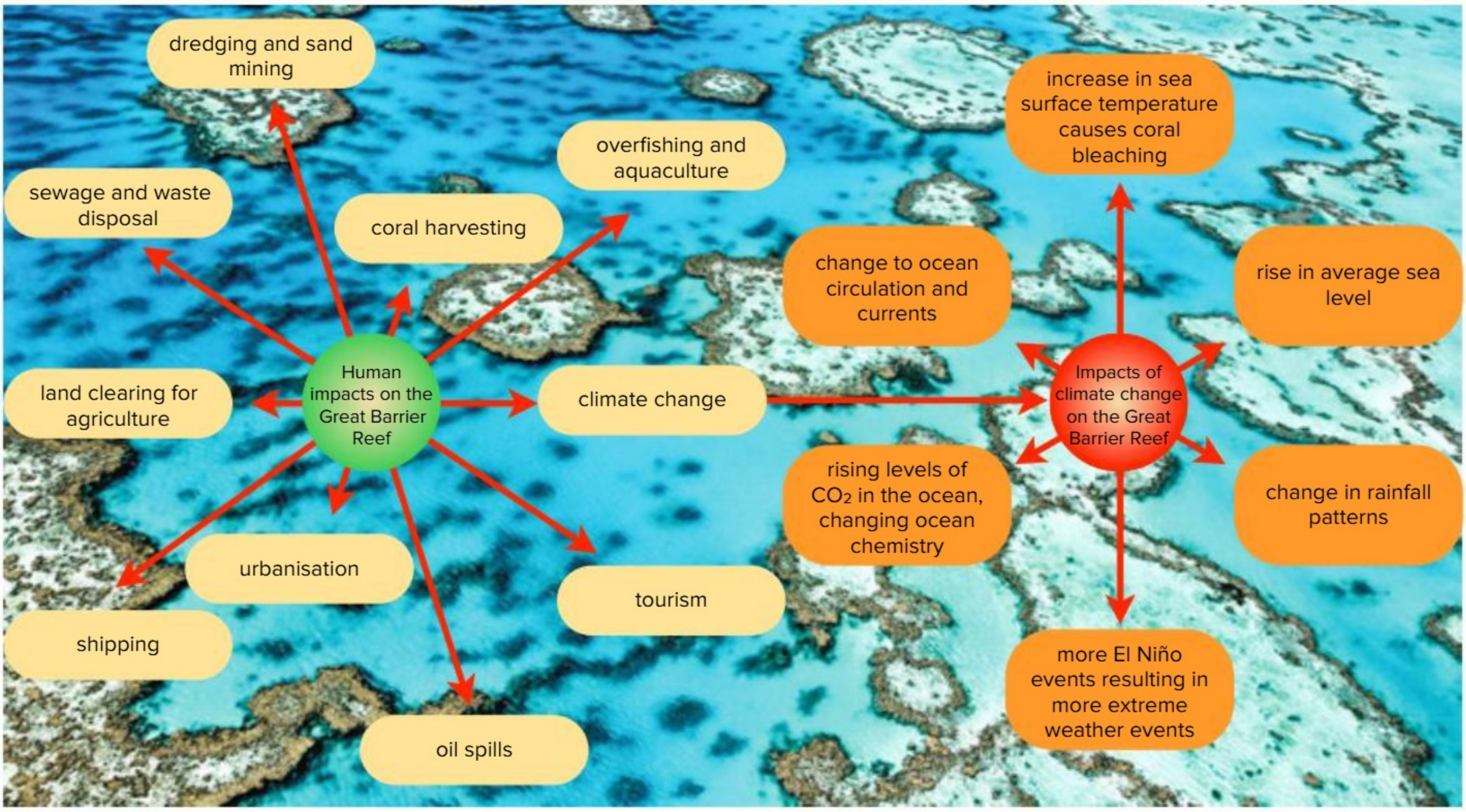


**3.81** An underwater view of a section of the Great Barrier Reef near Cairns that was devastated by a hurricane almost six years before this photo was taken. Apart from a few slow-growing boulder corals, all the coral has been shattered by wave action during the hurricane. Most damage was to branch coral, which is vulnerable to storm waves, but fortunately re-grows within a decade or two.

As well as having substantial value as a unique environment with diverse ecosystems, the Great Barrier Reef has high **economic value**. About two million people from around the world visit the Great Barrier Reef each year, bringing about $US5 billion annually to the region's economy and supporting almost 70,000 jobs. The non-tourism value of the Reef can also be taken into account by adding estimates of the economic worth of factors such as fishing, protection of the coastline from damaging ocean swells, the potential of plant and animal species to provide cures for diseases, and the value of protecting indigenous culture. When this is done, the TEV (Total Economic Value) rises to between $US12 and $US16 billion.

Not surprisingly, many incompatible land-use demands are made upon the Great Barrier Reef that have resulted in **conflicts** requiring careful management. Human activity on the Great Barrier Reef has a **long history** as Aboriginal and Torres Strait Islander people have fished and hunted on the reefs for thousands of years. A significant turning point occurred in the early 1970s when there was a major government investigation into the possibility of oil mining on the Great Barrier Reef. The conclusion was that oil exploration should not be permitted, and furthermore a government authority should be established to protect and manage the Reef from such threats in the future. Consequently, the **Great Barrier Reef Marine Park Authority** (GBRMPA) was established in 1975. In 1981, the Reef was added to UNESCO's list of **World Heritage** sites, making it the world's largest World Heritage area.

**Management** of the Great Barrier Reef is a **complex** task that aims to ensure a **balance** between human




3.82 Significant human impacts on the Great Barrier Reef, including the impacts of climate change as predicted by the Great Barrier Reef Marine Authority.


3.83 Catamarans taking tourists for day trips from Cairns to the Great Barrier Reef.

use of the area while protecting its natural and cultural features.

As the main industry in coastal Queensland, **tourism** has a significant impact on the Great Barrier Reef. More than 85% of tourists visit the Reef in offshore areas around Cairns, Port Douglas and the Whitsunday Islands. These areas comprise less than 10% of the area of the Marine Park, so the human impact is **highly concentrated** in these areas. There are six main ways in which tourism impacts the ecosystems in the Great Barrier Reef marine environment:

- **Tourist infrastructure.** Most visitors to the Great Barrier Reef stay in hotels or resorts, many of which have been built on fragile beach areas on the mainland. The hotels and resorts produce wastes, including sewage, that are disposed of through estuarine environments to the coastline.

3.84 Hotels line the coast in Cairns. Pipes empty stormwater from the hotels and nearby residential areas into the sea.

- **Boating.** Each year, sightseeing and diving boats make thousands of journeys around the Reef, bringing rubbish and the potential for oil spills. The boats require moorings and anchorages on the outer reef that destroy the coral.

3.85 In addition to the large boats that take tourists to the Great Barrier Reef from coastal towns, smaller boats operate close to the reef to transport divers and provide sightseeing. These small boats include glass-bottomed boats and semi-submersible vessels as shown here, where tourists view the reef formations and marine life through windows below water level.

3.86 Pontoons moored in shallow water provide a base for tourists who travel by boat for a day on the Great Barrier Reef.

- **Island tourism.** There are several islands in the Great Barrier Reef where resorts, pontoons and airstrips have been constructed. Use of this tourist infrastructure creates rubbish and wastes that require disposal.

- **Water-based activities.** Although diving and snorkelling do not damage coral when done responsibly, some swimmers get too close to the corals, including the especially fragile branching corals, breaking them.

- **Interaction with wildlife.** Although most tour operators ensure that tourists do not get too close to wildlife, some tourists do approach fish and animals too closely, disrupting breeding, causing injuries and changing natural movement patterns.

3.87 A tourism pontoon on Moore Reef, near Cairns.


3.88 Snorkelling is a popular water activity in the shallow waters of the Great Barrier Reef as it enables tourists to see the colourful fish and corals at close range.

- **Destruction of coral.** Coral is damaged when tourists walk on it (a practice that was once common but which is now illegal) or when they take coral as a souvenir (also illegal).

Other economic activities also affect the Great Barrier Reef. Fishing and aquaculture are significant activities in the areas in and near the Great Barrier Reef Marine Park. Commercial **fishing** sometimes depletes stock to the extent that breeding is affected. In **aquaculture**, commercial farming of oysters, pearls and fish is undertaken in large ponds, and this may release chemicals, pollutants and diseases that affect the Reef's other wildlife.

**Agriculture** on the mainland along the Queensland coast can also affect the Great Barrier Reef ecosystems. When **land is cleared** for farming, erosion of the soil washes sediment into the oceans, increasing **turbidity** (cloudiness of the water) and

3.89 Sugar cane farms beside the coastline, overlooking the Great Barrier Reef north of Cairns.

thus placing stress on marine wildlife. Furthermore, excess **chemical fertilisers** used on farms washes down to the ocean through coastal rivers. When the fertilisers reach the ocean, they increase the nutrient levels which in turn results in algal growth in coastal waters. The algae multiply, smothering the reefs and reducing light penetration through the water.

A significant human impact on the Great Barrier Reef arises through anthropomorphic (human-induced) **climate change**. Aquatic life is highly dependent on stable temperature conditions, and even small fluctuations in water temperature can be enough to kill many marine organisms. It is not just changes in temperature that affect coral reefs, but the speed at which these temperature changes occur.

The growth of coral reefs relies on the mutually dependent (symbiotic) relationship between **zooxanthellae** and the **coral polyp**. For this relationship to work effectively, sunlight, clear oceans and warm water are all required. If the water gets too warm, even by a small amount, the coral polyp expels the zooxanthellae and the relationship is destroyed.

As coral gets its colour from the zooxanthellae, all that remains of the reef after this process are the white skeletal remains of the coral, a condition known as **coral bleaching**. Coral bleaching is a stress reaction, and a reef may take many years to recover. In extreme cases, the coral may die, and this leads to a domino effect through the food chain as nutrients become unavailable for other organisms. If water temperatures of the ocean continue to rise in the years and decades ahead due to climate change, coral bleaching will become an increasingly significant problem.

Coral bleaching already affects large areas of the Great Barrier Reef, especially in the warmer waters towards the north as shown in figure 3.76. The process of bleaching is accelerated during **El Niño** events such as occurred in 1982, 1998, 2002 and 2016. In the bleaching event of 2016, surveys showed that 93% of the individual reefs had been affected to some extent by bleaching, and 22% of all the coral in the Great Barrier Reef had been killed.

Climate change has other impacts on the Great Barrier Reef besides coral bleaching. **Rising sea levels** will cover the reefs, forcing the coral to grow upwards to survive. Global warming leads to more frequent **hurricanes** and severe storms that can damage or destroy coral reefs. The **chemical composition** of the water is likely to change as more carbon dioxide is dissolved in the seawater, which in turn is likely to affect marine species that cannot adapt to even small changes in the chemical balance. Changes in the **migration** patterns of sea birds have already been observed. This has led to a decline in bird numbers as the adult birds are flying over distances that are beyond their endurance to find food as the availability of fish declines as a consequence of changed circulation patterns and currents.

As the temperature of the oceans rise, larger species are also affected. Water temperature influences the gender of new-born **turtles**, with more females being born when ocean temperatures are warmer. An emerging gender imbalance has already been observed due to rises in water temperatures. Turtles are also affected by rising sea levels, as their nesting sites are on beaches that are slowly being covered by rising waters.

Changes in ocean currents are affecting the location, timing and frequency of **upwellings** that bring nutrients from the sea floor to the surface waters of the Great Barrier Reef. The upwellings attract fish, which in turn affect predators such as sharks, dolphins and sea birds. Changes in the nutrient upwellings have already resulted in a decline in fish numbers. If the scale or extent of this process increases, more and more species through the food chain are expected to be impacted.

**Indigenous people** practiced traditional management of the Great Barrier Reef over the centuries before the arrival of Europeans. **Aboriginal groups** lived along the Queensland coast where they hunted animals and gathered plants. Unlike Aboriginal peoples, **Torres Strait Islander groups** used boats to harvest fish and other marine life from the reefs. The impact of these groups on the ecosystems was negligible as population numbers were small, and they took only enough resources to meet their immediate needs. Traditional management was thus **sustainable**, meaning it could have continued indefinitely if no other factors changed the situation.

Indigenous groups continue to manage aspects of the Great Barrier Reef. Since 1992, Indigenous Australians have been given **legal title** over many of their traditional lands, and today more than 70 indigenous groups have been given title over various islands, reefs and portions of the Great Barrier Reef coastline. **Indigenous management** is achieved by collective community management through an organization established by the GBRMPA called the **IPLU** (Indigenous Partnerships Liaison Unit). The IPLU is a mechanism through which Aboriginal and Torres Strait Islander peoples can have a say in how the Reef is managed and allow traditional practices, such as subsistence fishing, to continue in areas where such practices are now illegal for other groups.

**Government jurisdiction** over the Great Barrier Reef rests with the Australian **national government** that is based in Canberra. This is because the area has been listed by UNESCO as a World Heritage Site, and therefore becomes a responsibility of the country's international **treaty obligations**. The Australian Government receives advice from the GBRMPA on actions that may be required in the areas of research, marine transport safety, fishing and quarantine. **Local councils** administer the coastal areas that are situated beside the reef. Their responsibilities include the important role of approving or vetoing proposed development applications and land-uses along the coastline that might affect the Reef.

The GBRMPA manages the Reef through a **Zoning Plan** that was implemented in 2004. The zoning plan is designed to permit certain human activities to take place within the Marine Park that do not degrade the natural environment or its ecosystems. Under the Zoning Plan, commercial fishing is confined to particular sections of the Marine Park, and tourism developments such as pontoons are restricted to designated zones.

In an effort to improve the **water quality** of the Great Barrier Reef, the Reef Water Quality Protection Plan (commonly known as the **Reef Plan**) was implemented in 2003, and updated in 2009 and 2013. The Reef Plan's **goal** is "to ensure that by 2020 the quality of water entering the reef from (mainland) land use has no detrimental impact on the health and resilience of the Great Barrier Reef". This goal is to be achieved through ambitious **targets** to reduce nitrogen loads, sediments and pesticides entering the Reef's waters from land use activities on the mainland. These targets will involve significant changes to land-use practices by sugar cane farmers, horticulturalists and graziers in the years ahead, as well as providing additional care for natural wetlands to ensure there is no net loss to mangroves along the coastline.


**3.90** A notice on a pontoon in the Great Barrier Reef outlines the regulations relating to water quality that must be obeyed.

Recent proposals continue to pose significant threats to the health of the Great Barrier Reef. In late 2015, a controversial proposal to expand a **coal-loading port facility** at Abbot Point near Bowen in North Queensland was approved by the Australian Government. This project, located about mid-way between Townsville and Mackay, will create one of the world's largest coal-loading ports on the coastline of the Great Barrier Reef Marine Park, about 19 kilometres from the nearest coral reef.

Construction will involve dredging 1.1 million cubic metres from the sea floor that will then be dumped on land. In approving the project, the government stated that strict **environmental conditions** would been placed on the port's expansion, including monitoring the water quality around the area, monitoring ship movements, and making sure that dredge spoil does not go back into the ocean.

## Question Bank 3G

1. *Outline the location and extent of the Great Barrier Reef.*
2. *What is significant about the Great Barrier Reef that justifies its listing by UNESCO as a World Heritage site?*
3. *What are the main natural stressors that affect the Great Barrier Reef?*
4. *Describe the likely effects of climate change on the future of the Great Barrier Reef.*
5. *Outline the impacts of climate change on the Great Barrier Reef that can already be observed.*
6. *What are the impacts of tourism on the Great Barrier Reef?*
7. *On balance, do you think tourism is a force to destroy or a force to protect the Great Barrier Reef? Give reasons for your viewpoint.*
8. *Apart from tourism and climate change, what do you consider is the most significant human impact, or potential human impact, to the environment of the Great Barrier Reef?*
9. *Outline the past and present relationship between indigenous peoples and the Great Barrier Reef.*
10. *List the significant stakeholders in managing the Great Barrier Reef, and outline the perspective of each on the value of the Reef and its uses.*
11. *State your opinion of the top three threats to the Great Barrier Reef, and for each threat, explain briefly what you think should be done to manage the Reef effectively.*

## The development of mangrove swamps, and their value

**Mangroves** are a type of tree that grows in muddy, chiefly tropical coastal swamps that are exposed at low tide but flooded at high tide. Mangroves usually have a mass of tangled roots above ground and they form dense thickets. Because they need to survive in oxygen-starved (anaerobic) environments, they use aerial roots known as **pneumatophores** to survive.

Because they are difficult to penetrate and often have a foul smell (caused by the anaerobic conditions), mangrove swamps used to be considered an undesirable waste of space and they were often cleared away. Today, we understand the value of the mangrove swamps more clearly, recognising that mangroves are among the world's most productive ecosystems.

**3.91** These mangroves are growing on a tidal flat in Moreton Bay, Queensland (Australia). In this view, the flats are in the process of being covered by the waters of a rising tide.

Mangroves play an important part in **stabilising tidal flats** by slowing the movement of water around their roots. This causes the sediment in the water to be deposited, providing a foundation for halophytic (salt-tolerant) plants to establish themselves. In this way, mangroves serve as the **pioneer vegetation community** in many tropical estuaries, helping mud flats to form that can then support other types of vegetation, causing more deposition to occur, which leads to the expansion of the mud flats, and so the process continues.

Mangroves form best in calm, sheltered waters where there is **little wave action**. Because their extensive root systems are very efficient in dissipating wave energy, mangroves serve a useful role in **protecting** coastal areas from erosion, including extreme events such as surge storms and tsunamis. For this reason, mangroves are increasingly seen as an important element in conservation programs, especially where biodiversity is being encouraged.

In the aftermath of the large **tsunami** in the Indian Ocean in December 2004, it was found that coastlines protected by mangrove swamps were less damaged than areas without protective vegetation, and if the density of mangroves was at least 30 trees per 100 square metres then the maximum flow of the tsunami was reduced by about 90%.

For biologists, mangroves are seen to have special value because they **support unique ecosystems**, especially on a microscopic scale within their intricate root systems. Furthermore, the sheltered environment of the mangroves' root system provides **spawning grounds** and an attractive environment for many young marine organisms. Indeed, two-thirds of all the **fish** that are caught around the world each year breed in wetlands.

**3.92** Mangroves near Airai, Palau. In this view, it can be seen that the pneumatophores aid the process of natural reclamation of land from the sea. This occurs because the pneumatophores calm the local waters, allowing the fine mud and silt to settle through the process of deposition.

Mangroves provide other important biological functions such as the **purification** and **detoxification** of wastes by filtering pollutants out of the water. Some mangrove swamps have been found to reduce the concentration of nitrates in waste water by more than 80%.

In less economically developed countries, mangroves provide **fuelwood**, building materials and traditional **medicines**.

## Threats to mangrove swamps

It is estimated that almost half of the world's mangroves have been **destroyed by humans** who, until recently, often regarded mangrove swamps as 'wastelands' or 'useless swamps'. Current estimates are that 15 million hectares of mangroves remain in the world, a significant loss from the natural figure of 32 million hectares. According to the Food and Agricultural Organisation (FAO), about 150,000 hectares of mangroves are lost each year, representing an annual loss of 1%.

This destruction is **not evenly distributed**. Since 1960, Thailand has lost half of its mangroves, and the Philippines has lost almost 80% of its mangroves since the 1920s.

Mangroves are cleared for a variety of reasons, including **commercial harvesting** of their durable and water resistant wood, medicines, tea, livestock feed and charcoal production. All these uses destroy the mangroves. However, the United Nations Environment Program (UNEP) estimates that the biggest danger to mangrove swamps is clearance to make way for **shrimp aquaculture**. The UNEP estimates that 25% of the destruction of mangrove forests comes from this cause alone.

However, this view is disputed by academic research in the 'Journal of Biogeography' which claims that the **expansion of agriculture** is the most significant cause of mangrove destruction. According to this research undertaken by the Chandragiri Science Application International Corporation (CSAIC), which analysed over 750 Landsat satellite images covering most tropical coastal parts of Asia, 81% of mangrove swamp destruction over the 30 year period from 1975 to 2005 was the result of agricultural expansion. Shrimp aquaculture accounted for a further 12% while urban development contributed another 2%.

Conservationists worry about the long-term consequences of this loss, especially with respect to the loss of habitat and breeding grounds that results. One response to this concern has been the signing of an **international treaty** for the conservation and sustainable use of wetlands. Known officially as the Convention on Wetlands of International Importance, it is more commonly known as the **Ramsar Convention**, named after the city of Ramsar in Iran where the treaty was signed in 1971.

A total of 169 countries have signed the Ramsar Convention, committing to three key policies:
- **using** the wetlands in their country wisely;
- **designating** suitable wetlands for the 'List of Wetlands of International Importance' (the "Ramsar List") and ensuring their effective management; and

- **co-operating** internationally on transboundary wetlands, shared wetland systems and shared species.

The **Ramsar List** of significant wetlands includes more than 2,200 locations covering a total of almost 2.2 million square kilometres.

## QUESTION BANK 3H

1. *What benefits do mangroves bring to humans?*
2. *What are the causes and consequences of the loss of mangrove swamps?*
3. *What is the Ramsar Convention, and why is it significant?*

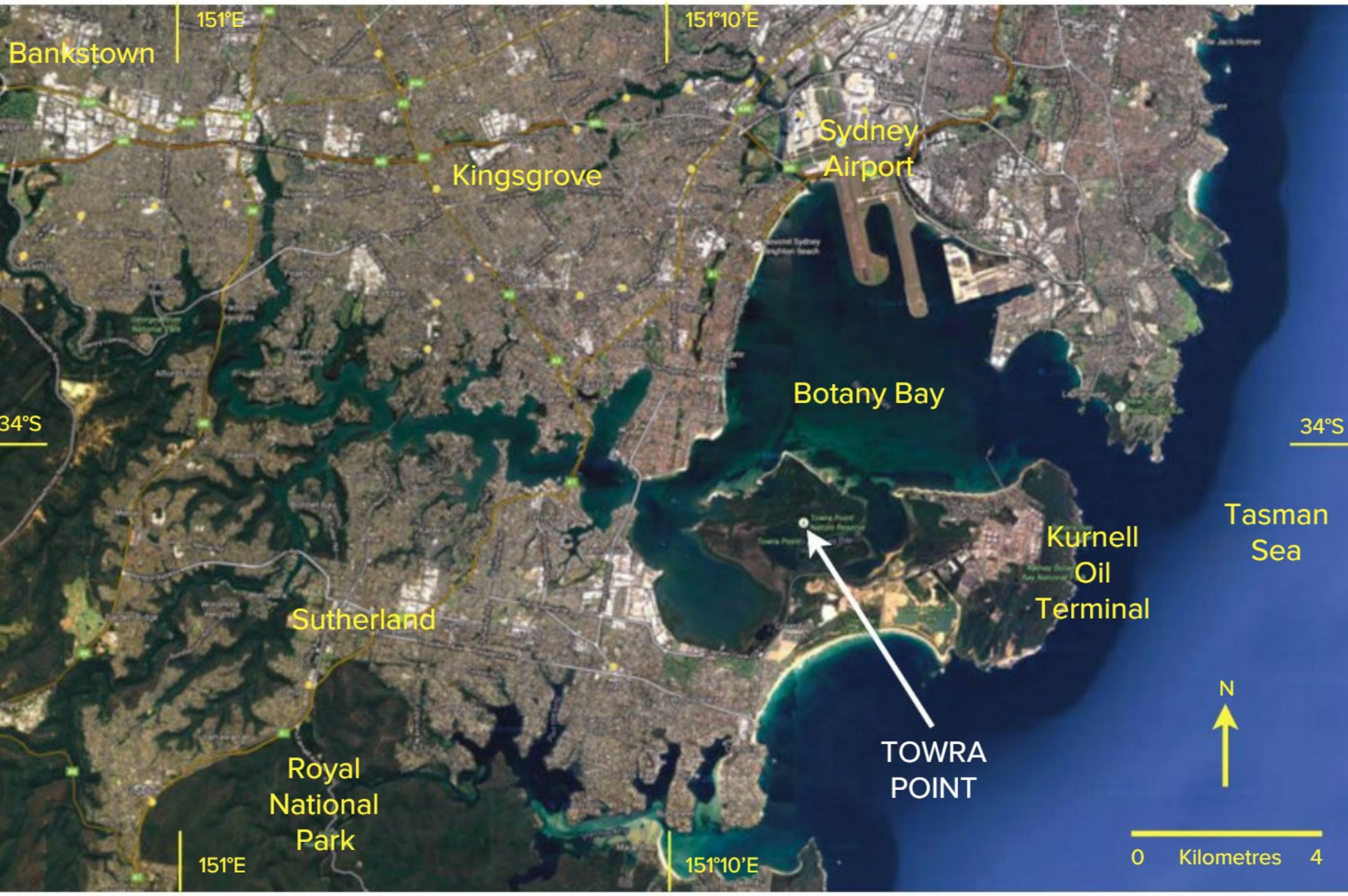
## CASE STUDY
## Management of Towra Point mangrove swamps

With 400 hectares of mangroves, 600 hectares of seagrass and 160 hectares of saltmarsh, **Towra Point** is the largest **wetland** in the Sydney Region. Its management is an important **sub-set** of Sydney's coastal management that was described earlier in this chapter.

Located on the southern edge of Botany Bay in Sydney's southern suburbs, Towra Point is about 16 kilometres south of the Sydney CBD. Its precise location is 34°S, 151°10'E. It is somewhat remarkable that a large wetland area like Towra Point can exist largely in its natural state within the metropolitan area of a city with over 4 million people close to an international airport, a port facility and an oil refinery.

Of the 400 hectares of mangroves at Towra Point, 386 hectares are included in the **Ramsar List** of internationally significant wetlands because of the following characteristics:

- it is a particularly **good representative example** of a natural or near natural wetland, and is characteristic of the bioregion;
- it supports an assemblage of **rare, vulnerable or endangered** plant or animal species, or an




3.93 Towra Point Nature Reserve is the dark green area of mangroves located on the southern side of Botany Bay in the southern suburbs of Sydney, Australia. Source: based on Google Maps.

appreciable number of individuals of any one or more of those species;

- it is of value for maintaining the genetic and ecological **diversity** of the region, because of the quality and peculiarities of its flora and fauna;
- it regularly supports substantial numbers of individuals from particular groups of **waterfowl;**
- it regularly supports **1% of individuals in a population** of a species or subspecies of waterfowl; and
- it supports populations of **waders** such as the Pacific golden plover (*Pluvialis fulva*), double-banded plover (*Charadrius bicinctus*), eastern curlew (*Numenius madagascariensis*) and ruddy turnstone (*Arenaria interpres*), which regularly exceed 1% of the entire Australian population.

Towra Point contains **two types** of mangrove. The dominant species is the **grey mangrove** (*Avicennia marina*), found in the salt waters of Botany Bay and the lower reaches of two tributary rivers, the Georges River and the Woronora River. The less common species is the **river mangrove** (*Aegiceras comiculatum*), a dwarf type of mangrove which is found in less saline areas that seldom grows higher than 2.5 metres.

The mangroves provide an important role in the **food chain** of the local ecosystem. Each year, the mangroves at Towra Point drop about 2,500 tonnes of dead leaves, bark and fruit, which is colonised by bacteria and microscopic fungi after the soluble nutrients have been leached. This decomposed material is consumed by small animals such as crabs and prawns, which in turn are eaten by **water birds**. About 70 species of birds use the mangrove swamp at Towra Point. It is an important habitat for wading birds that find space for roosting at high tide, and for other birds that feed on the mud flats at low tide.

**3.94** Grey mangroves (*Avicennia marina*) at low tide in Botany Bay.

**3.96** Water birds in the mangroves at Towra Point.

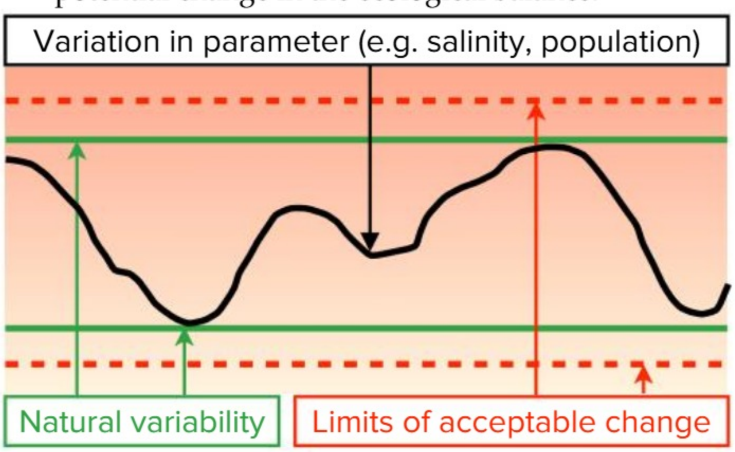
**3.95** River mangroves (*Aegiceras comiculatum*) at Towra Point.

Accompanying the mangrove wetland is another swampy area of **saltmarsh**. The saltmarsh contributes to the ecological health of the mangroves as it acts as a buffer zone between the mangroves and the nearby urban areas. The saltmarsh filters noise and pollution from the urban areas, and they increase the biodiversity of Towra Point, thus expanding the range of bird and animal species. The saltmarsh helps to recharge the groundwater, which affects the surface elevation and therefore the extent of flooding through the mangrove area that the mangroves depend upon on a daily basis.

3.97 Saltmarsh at Towra Point.

Not surprisingly, given Towra Point's location within Sydney's suburbs, there are significant **threats** to Towra Point's environment arising from human activity. Migratory bird habitats and wetlands are being lost or damaged as a result of nearby development and recreational uses, and this is resulting in declining species diversity. Severe wave action is eroding the wetland's shoreline, which in turn undermines the vegetation. Although access to Towra Point is heavily restricted, requiring prior planning and official written permission from government authorities, there are growing impacts from introduced plants and animals, camping, horse riding, boating and other recreational activities around the edges of the reserve.

Towra Point is under the day-to-day **management** of the New South Wales National Parks and Wildlife Service (NPWS). NPWS officers monitor changes in the components or processes in the Towra Point environment that may indicate a potential change in the ecological balance.




3.98 Example of natural variability and the limits of acceptable change. These limits can be used in Towra Point to trigger management authorities to take action.

Figure 3.98 shows the **simplified conceptual model** that is used by management authorities. Limits of acceptable change are identified and defined for various parameters that fluctuate within a range of natural variability. These variables include climate (temperature and rainfall), changes in sea level, sedimentation levels, tidal changes, wave action, turbidity, changes in the level of groundwater, salinity levels in the water, the chemical and nutrient balance, animal and insect numbers, the balance of bird species, and changes in the mangroves themselves. Any of these limits may be used to trigger action by management authorities.

## Seven threats to Towra Point's environment

Figure 3.100 shows how these limits of acceptable change are applied in Towra Creek by management authorities. Seven **key threats** to Towra Point's environment have been identified. These are shown in the top horizontal axis of figure 3.100 and considered in turn in the paragraphs below. The seven threats are monitored through five facets of the environment — the marine environment, the landforms, animal and plant habitats, the physio-chemical balance of the environment, and the state of mangroves and other plants in the area.

### 1: Weeds and pests

**Weeds and pests** used to one of the biggest threats to Towra Point, but as figure 3.100 shows, this threat is decreasing. In the 1800s, Towra Point was used for animal grazing and timber cutting, and the resulting site disturbance enabled noxious weeds to invade and become established. Although the


3.99 Bitou bush in Towra Point.

| | Weeds and pests | Altered landforms and water cycle | Urban and industrial develop-ment | Pollution | Inapprop-riate recreation | Mangrove encroach-ment | Climate change |
|---|---|---|---|---|---|---|---|
| **Marine environment** | ↘ | ↗ | ☝ | → | → | → | ☝ |
| **Landforms** | ↘ | ↗ | ☝ | → | ↘ | → | ☝ |
| **Animal & plant habitats** | ↘ | ↗ | ☝ | ↘ | ↘ | → | ☝ |
| **Physico-chemical balance** | ↘ | ↗ | ☝ | ↘ | → | → | ☝ |
| **Mangroves, plants** | ↘ | ↗ | ☝ | ↘ | ↘ | → | ☝ |

| | | | | |
|---|---|---|---|---|
| Impact on the elements and processes of the mangrove community | low | moderate | high | very high |
| On current trends, the level of impact is ... | ↘ decreasing | → continuing | ↗ increasing | ☝ increasing rapidly |

3.100 Threats to the ecology of Towra Point Nature Reserve Ramsar site. Source: Adapted from Towra Point Nature Reserve Ramsar Site Ecological Character Description (2010), p.101

elimination of these activities has reduced the threat from invasive weeds, the risk is still serious.

The biggest weed threats are bitou bush, lantana, blackberry bushes and asparagus fern. **Bitou bush** is a weedy shrub that originated in South Africa and has invaded large areas of eastern Australia. In Towra Point, bitou bush has spread rapidly, suffocating native plants, preventing native seed germination, threatening biodiversity and thus reducing the food supplies for native animals. Bitou bush seeds are spread by birds and foxes (another introduced pest), and to a lesser extent by wind and water movement. Attempts to control bitou bush have involved spraying the ground with glyphosphate and hand removal of weeds by contract workers.

The main pest threats in Towra Point are **introduced animal species** such as foxes, cats, rabbits, ravens, ants and rats. The biggest threats are posed by **foxes**, which hunt and kill native birds and animals, disturb roosting birds, compete for food and resting places, and spread the seeds of noxious weeds. Cats are a significant threat because Towra Point is near residential areas.

The main **strategy** used to control foxes is to lay baits of meat containing poisonous sodium mono-fluroacetate (also known as '1080'), while other techniques to control animal pests include trapping, shooting and fumigation of animal dens.

3.101 Invasive asparagus fern covers much of the ground in this area of Towra Point, soaking up much of the ground moisture.

## 2: Altered landforms and water cycle

Changes in the area's **landforms** also affect the movement of **water** in a coastal environment such as Towra Point where dredging, land reclamation, water harvesting and multiple uses of the surrounding catchment area are practised. For example, **dredging** is often done at the entrance of Botany Bay to the sea to enable large ships to use the port facilities and oil terminal wharf in the bay. Dredging has the effect of changing the **wave pattern** in the bay, thus altering the distribution of **wave energy** along the shoreline. Dredging allows larger waves to enter Botany Bay, and the extension of Sydney Airport's runways into Botany Bay by land reclamation has caused these stronger incoming waves to be reflected across to Towra Point. As a result, **erosion** of the wetland area has increased, reducing the overall area of swamp.

3.102 Water management within the Towra Point mangrove swamp; large concrete pipes allow water to flow from one side to another of an elevated causeway that was built during the 1940s to service a radar station that was built at the time.

In addition to the continuing dredging of the entrance of Botany Bay, dredging is being expanded with several new projects, including a new pipeline for a water desalination plant and the placement of additional underground electricity cables in the shoreline environment.

Other changes to the water cycle in Towra Point have resulted from **inappropriate water use**, such as groundwater extraction, sand mining and water harvesting. Although these activities can be undertaken sustainably, inappropriate use of water is posing threats to the mangroves in Towra Point. For example, **sand mining** was undertaken to the east of Towra Point near the Kurnell Oil Terminal from the 1930s until 1990.

3.103 Towra Point's mangroves are susceptible to very minor changes in sea level as the tidal mudflats have such a shallow gradient.

3.104 While it operated, sand mining on Kurnell Peninsula exposed the groundwater, resulting in the large lake visible in this oblique aerial view. The close proximity to Towra Point, which is the dark green area of mangroves in the right background, can be seen clearly in this view.

The sand mining has exposed a **groundwater aquifer**, resulting in flooding of some of the sand mining area, contamination of the groundwater and an increased rate of evaporation of the groundwater, lowering the water table (upper limit of the saturated zone of groundwater) under the mangroves. This has reduced the area of saltmarsh, leading to the expansion of mangroves into areas that were previously saltmarsh, changing the relative balance between saltmarsh and mangroves in favour of mangroves. The changing balance between these two swamp environments has reduced the numbers and species diversity of the birds, turtles, fish and frogs in the Towra Point environment.

The **response** of management authorities to alterations in the water cycle has been to model and propose changes to the water and sediment inputs into Botany Bay. Another proposal is to collect baseline water quality data to determine the acceptable change to groundwater quality with a view to developing a strategy on groundwater management.

### 3: Urban and industrial development

The catchment area of rivers that drain into Botany Bay contains a **rapidly growing population** that already numbers almost 2 million people. Urbanisation of the catchments places considerable stress on the environmental quality of Botany Bay, including the Towra Point mangrove swamps. Urban development increases the percentage of land covered by **hard surfaces**, which reduces **infiltration** after rainfall, thus increasing the **runoff** into rivers that empty into Botany Bay. The clearance of bushland to expand urban areas also reduces the **habitats** for native animal species. The fragmentation of their territories increases the likelihood of being replaced by introduced species, such as feral cats. The introduction of **domestic plants** and **weeds** also has the potential to reduce the biodiversity of native vegetation by bringing competitor species into the environment.

A particular threat arises from the close proximity of a large **oil terminal** to Towra Point. The Caltex Oil Terminal at Kurnell is situated just four kilometres from the centre of Towra Point Nature Reserve, and until 2014, it operated as an oil refinery. Although the terminal is subject to strong environmental regulations, there is a risk that tankers may **spill oil** while they are unloading fuel at the nearby pier. An incident occurred in 1979 when a ship called the 'World Encouragement" spilt 95 tonnes of oil into Botany Bay. This resulted in the death of large numbers of fish in Botany Bay and oiling of the shoreline that killed mangroves in some parts of Towra Point. Should this happen again on a larger scale, oil would cover the pneumatophores of the mangroves, killing the trees, which could lead to the death of the entire ecosystem. Since the conversion from a refinery to an oil terminal in 2014, this threat has been reduced somewhat, as refined fuel rather than crude oil is now unloaded from ships, posing a lesser environmental danger.

3.105 The large facility in the middle of this photo is the Caltex Oil Terminal on Kurnell Peninsula, where oil is stored after being imported from overseas before being distributed through Australia. Until October 2014, this was an oil refinery. The facility in the foreground is a desalination plant. The entrance of Botany Bay to the Tasman Sea is shown in the background. Towra Point is off to the left of this view.

The oil terminal also threatens the quality of the **groundwater** that was exposed nearby in the sand mining area. Significant hydrocarbon contamination occurred while the oil terminal operated as an oil refinery, and contaminated groundwater flows underground to Towra Point.

The **management strategies** to address issues of urban and industrial development include maintaining wildlife corridors in nearby urban areas, ensuring that storm water pipes that drain urban and industrial areas are maintained well, and increasing community awareness of sound environmental practices.

3.106 A tanker ship delivers refined fuel to the Kurnell Oil Terminal in Botany Bay.

## 4: Pollution

Further pollution threats arise from the close proximity of Towra Point to **container port** and **international airport**. These facilities are located on the northern side of Botany Bay, less than five kilometres from Towra Point's mangroves. Towra Point is situated under the main take-off and landing paths for Sydney Airport, resulting in the deposition of ultra-fine carbon particles on Towra Point.

**3.107** Household rubbish and building wastes have been dumped among the mangroves in Towra Point. Rubbish such as this leaches toxic chemicals into the swamp water, poisoning some plant and animal species.

**3.108** A dumped old truck in Towra Point. Rusting car and truck bodies provide habitats for feral animals and introduced species, strengthening their position in the ecology of the area.

Another type of pollution affecting Towra Point's mangroves is **rubbish dumping**. Mangroves are often used as a dumping ground for rubbish, and Towra Point is no exception, even though access to the area is highly restricted. Towra Point is littered with rusting car and truck bodies, the remains of

**3.109** Rubbish left behind at an old oyster farming plant breaks down and releases poisonous materials, making the land toxic for mangroves that have been unable to re-establish in the area.

old industries that operated many decades ago, and household garbage. Such rubbish breaks down and pollutes the water in the swamp, while old car bodies provide shelter and habitats for feral animals and pests.

**Management strategies** to deal with pollution recognize that prevention of pollution at its source is the most effective approach. Therefore, strict pollution regulations regarding effluent quality are imposed on nearby industries such as the oil terminal, as well as shipping and airline companies that use the container port and the airport.

## 5: Inappropriate recreation

Botany Bay is a popular area for **recreational activities** such as swimming, fishing, bird watching, boating and bike riding. Some recreational activities have a **destructive effect** on the Towra Point mangrove community. Examples of such activities include motorbike riding through the mangroves at low tide, 4-wheel driving through the area, jet-ski use, and horse riding. Unlike most of Towra Point, permission is not required to gain access to the beach if approaching by boat, but even low impact activities such as picnicking on the beach can harm the mangroves if fires are lit or if litter is left behind. Furthermore, the boats that are used to gain access to the beach create waves that may disturb birds that use Towra Point as a nesting site, and they can destroy the seagrass beds by dragging anchors across the bottom of the bay.

The primary **management strategy** to reduce the risk of inappropriate recreation is to restrict public


**3.110** In an effort to protect its natural environment, entry to most of the Towra Point mangrove swamp is prohibited unless prior written permission has been obtained.

access to most of Towra Point. Gates and signs prevent unauthorised entry to Towra Point, and the Nature Reserve is patrolled on weekends during the bird breeding season by rangers. Apart from the beaches, the only part of Towra Point that is open to the public without prior written approval is a short boardwalk and viewing platform at Quibray Bay, which is located at the extreme eastern end of the Towra Point Nature Reserve. The viewing platform gives a view to the north across a highly disturbed section of mangroves and beyond to Botany Bay. It is proposed to increase education and signage emphasising the importance of Towra Point's environment as a means of reducing the threats posed by inappropriate recreation.

## 6: Mangrove encroachment

Monitoring of Towra Point's swamps by aerial photography since 1942 has shown that the **area** covered by **mangroves** has **increased** at the expense of the saltmarsh areas. The expansion of mangroves has been the main cause of the **decline of the saltmarshes**. Between 1956 and 1979, the area covered by mangroves grew by 34% while the area covered by saltmarsh declined by 62%. This is significant because, as we saw earlier, saltmarsh aids the health of the mangroves. Therefore, ironically, the expansion of mangroves into areas of saltmarsh is a threat to the health of the mangroves.

**Three factors** explain the encroachment of mangroves into saltmarsh areas. First, **rises in sea level** mean that additional low-lying areas of Towra Point are covered by water. More tidal inundation

**3.111** One of the few publicly accessible parts of Towra Point is Quibray Bay, where this elevated boardwalk gives visitors views across Botany Bay.

reduces soil salinity but increases soil moisture, conditions that favour mangroves. This forces the saltmarsh communities, which prefer more saline water than mangroves, to migrate inland. However, there is a limit to this migration because the southern edge of Towra Point is a built environment with roads, parks, buildings and manufacturing industries.

**3.112** Mangrove encroachment occurs as mangroves establish in areas of saltmarsh.

The second factor promoting mangrove encroachment is **sedimentation and subsidence**. Mangroves prefer calm moving water, where fine sediment is deposited around pneumatophores. The accumulation of sediments does not always raise the elevation of the mudflats because during periods of low rainfall, and low plant productivity, the water table drops, thus lowering surface elevation. Lowering the surface elevation increases tidal inundation, thus favouring mangroves over saltmarshes. This phenomenon is especially strong during warm ENSO (El Niño) events when drought conditions lower the water table significantly.

The third factor leading to mangrove encroachment arises due to **nutrient and sediment loads**. The catchments of the rivers that flow into Botany Bay have become heavily urbanised over the past 70 years, increasing the movement of sediments and nutrients into the waters of Botany Bay. Increased nutrient levels encourage the growth of both mangroves and saltmarsh communities. However, mangroves tend to benefit more than saltmarsh vegetation because mangroves out-compete saltmarsh for light because they are higher.

**Management strategies** in Towra Point are designed to protect the saltmarsh communities from mangrove encroachment. It is proposed to expand the area of the Ramsar site to provide additional protection to the saltmarsh zone, and to support this with a comprehensive study of the area's flora and fauna. One strategy that is no longer adopted is removing mangroves, because they simply regrow.

## 7: Climate change

**Climate change** results in sea level rise, warming temperatures, changing patterns of rainfall, growing intensity and frequency of storms, changing levels of atmospheric carbon dioxide and methane, all of which have the potential to affect mangroves in coastal areas such as Towra Point. Sea levels at Towra Point (and the entire Australian east coast) rose 1.2mm per year between 1920 and 2000, and it is expected that this rate of sea level rise will continue until at least 2050.

**3.113** An oblique aerial view of Towra Point.

**Rising sea levels** pose a threat to Towra Point's swamps because they affect tidal levels, which in turn affect the distribution and composition of plant species. As previously noted, this change is likely to decrease the area of saltmarsh as mangrove encroachment expands.

Average **atmospheric temperatures** at Towra Point rose by 0.9C° between 1950 and 2010. Projections suggest that average temperatures will rise by a further 0.9C° by 2030, and by an additional 1.6C° to 3.0C° by 2070. Measurements show that the rate of warming since 1950 is almost double the rate of warming between 1900 and 1950.

At the same time as atmospheric temperatures rose, **ocean temperatures** have also risen. On the east coast of Australia, ocean temperatures have risen since 1920, and this has accounted for part of the rise in sea levels. It is expected that ocean surface temperatures on the east coast of Australia will rise by another 0.3C° to 0.6C° by 2030.

Rising temperatures should favour the growth of mangroves at Towra Point as mangroves grow well in warm, tropical conditions. However, if average annual rainfall decreases and surface temperature increases, soil salinity will increase, thus limiting the expansion of mangroves. Since 1950, **average annual rainfall** has dropped in Sydney, and it is predicted to continue declining by 3% in the period to 2030, and between 4% to 8% by 2070. On the other hand, it is expected that the frequency and severity of **storms** will increase, and this is likely to increase rates of flooding, runoff and sedimentation in Botany Bay.

Associated with human-induced global warming is an increase in **atmospheric carbon dioxide**, and this promotes the growth of mangroves as they use the carbon dioxide for photosynthesis. Oceans **absorb** some of the atmospheric carbon dioxide, which makes the surface waters more **acidic**. An increase in oceanic acidity reduces the production of calcium carbonate shells by some marine organisms, which in turn changes the balance of composition of sediments, with consequent effects on the growing conditions for the coastal mangroves.

**Strategies** to address the issue of climate change are still being developed by Towra Point's management authorities.

**3.114** Climate change has considerable potential to change the delicate balance within the Towra Point ecosystem.

### Question Bank 3I

1. *Outline the location and extent of the swamps at Towra Point.*
2. *What is significant about the Towra Point ecosystem that justifies its inclusion in the Ramsar List.*
3. *Describe the Towra Point ecosystem.*
4. *Why is the relationship between the mangroves and saltmarsh important to the health of the ecosystem?*
5. *Rank the seven main threats to the Towra Point mangrove environment in your opinion of their descending order of importance, and justify your ranking.*
6. *Describe the importance of water in the Towra Point mangrove swamp, and summarise the threats to water quality in the area.*
7. *Describe the likely effects of climate change on the future of Towra Point's mangroves.*
8. *Explain briefly what you think should be done to manage the Towra Point environment effectively.*

# Geopolitics of oceans

## Sovereignty rights and EEZs

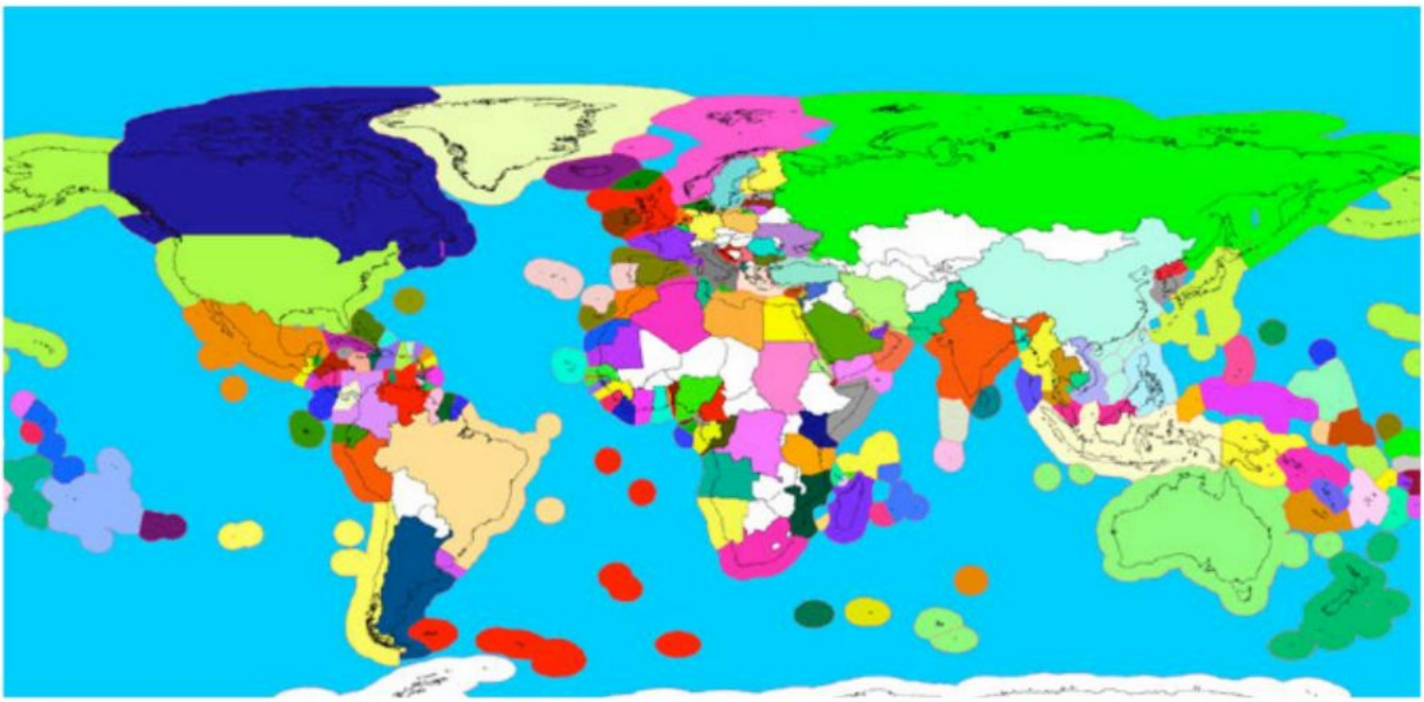
The territory of a country does not end at its shoreline. Countries that are connected to the seas or oceans have **sovereignty rights** over the section of water that is nearest to them. The extent of those sovereignty rights into the oceans is governed by the United Nations Convention on the Territorial Sea and the Contiguous Zone, which was approved in 1958. Among the key provisions of the Convention are the following points, which are quoted directly from the Convention (note that when the State is referred to, it means the nation-state, or the country):

- *The sovereignty of a State extends beyond its land territory and its internal waters to a belt of sea adjacent to its coast, described as the **territorial sea**.*
- *The sovereignty of a coastal State extends to the **air space** over the territorial sea as well as to its bed and subsoil.*
- *The normal **baseline** for measuring the breadth of the territorial sea is the low-water line along the coast as marked on large-scale charts officially recognised by the coastal State.*
- *In localities where the coastline is **deeply indented** and cut into, or if there is a fringe of islands along the coast in its immediate vicinity, the method of straight baselines joining appropriate points may be employed in drawing the baseline from which the breadth of the territorial sea is measured.*
- *Where the coasts of two States are opposite or adjacent to each other, neither of the two States is entitled, failing agreement between them to the contrary, to extend its territorial sea beyond the **median line,** every point of which is equidistant from the nearest points on the baselines from which the breadth of the territorial seas of each of the two States is measured.*
- *Subject to the provisions of these articles, ships of all States, whether coastal or not, shall enjoy the **right of innocent passage** through the territorial sea.*
- *The coastal State must **not hamper** innocent passage through the territorial sea.*
- *The contiguous zone may not extend beyond **twelve miles** (**22 kilometres**) from the baseline from which the breadth of the territorial sea is measured.*

Most countries would argue that 22 kilometres of territorial water is not enough to **guarantee security** from smuggling and other illegal activities, or to ensure adequate space for controlling illegal entrants. Therefore, the United Nations agreed to create **exclusive economic zones** (EEZs) beyond the 12 nautical mile (22 kilometre) territorial waters. In general, each country's EEZ extends for 200 nautical miles (370 kilometres) from the shoreline, or 188 nautical miles (348 kilometres) beyond the limit of territorial waters.

An exception to this rule occurs when the EEZs for two countries **overlap**. This occurs whenever their shorelines are less than 400 nautical miles (740 kilometres) apart. When this occurs, the two countries must define their actual boundaries. In general, the boundary is drawn along the **middle** of the line between the two countries.

Within its EEZ, a country has the **right** to explore, use, conserve and manage whatever natural resources are there. Countries may also use the EEZ to produce energy from the water, currents and winds. The pattern of control over the oceans arising from the combination of territorial limits and EEZs is shown in figure 3.115.



**3.115** National control over the world's coastal margins. Areas of blue ocean are international waters that are not under the sovereign control of any country.

## Conflict

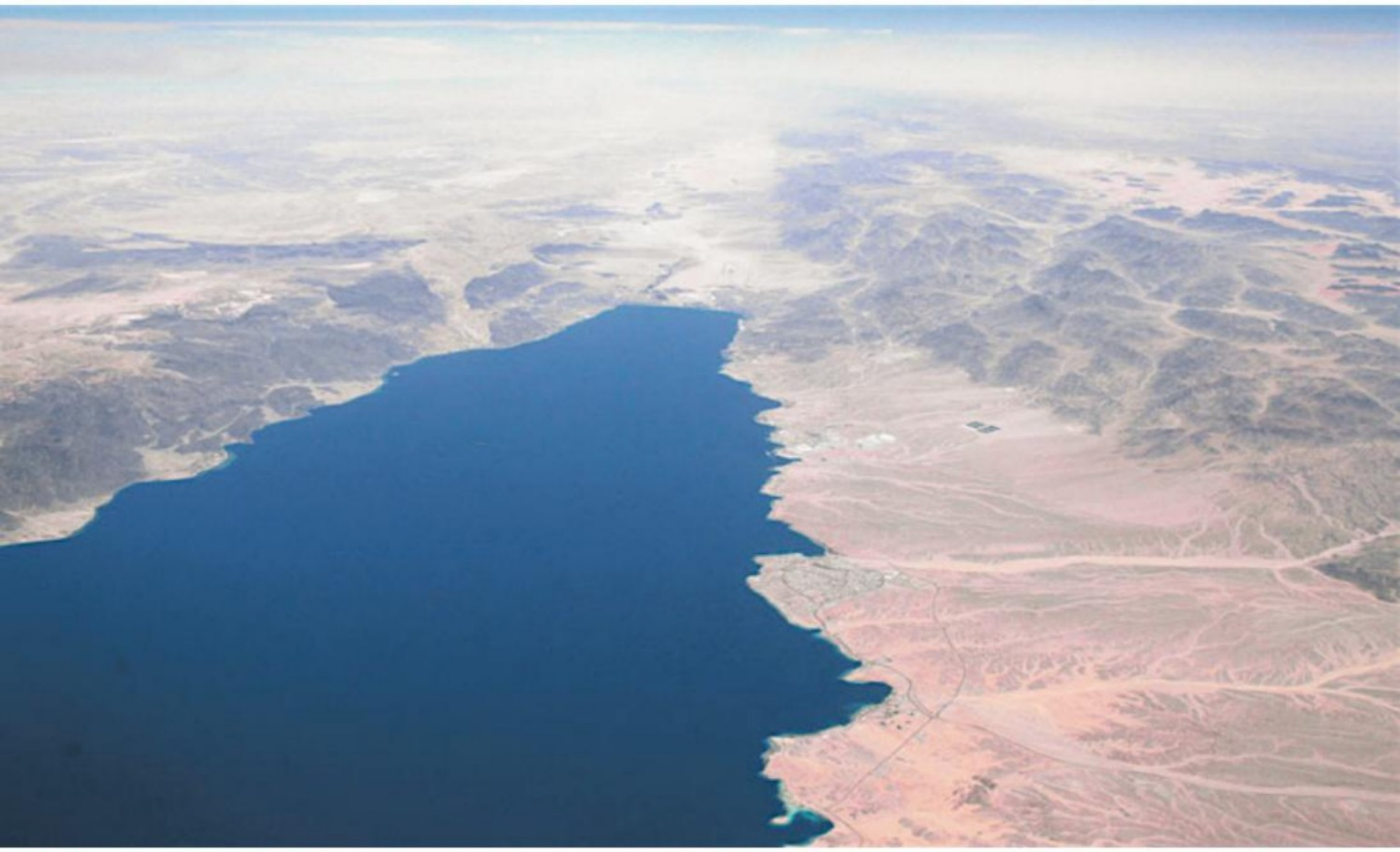
Countries are not always able to agree on the boundaries of their EEZs. This is especially the case when significant natural resources, such as oil, may lie beneath the ocean waters. Some conflicts have arisen between countries over the boundaries of their EEZs, including the following:

- the **Cod Wars** in the North Sea between the United Kingdom and Iceland from 1958, 1972 and 1976.
- the ongoing dispute over **Rockall**, a tiny rock in the North Atlantic Ocean, claimed by Ireland, the UK, Denmark and Iceland.
- the ongoing dispute over various islands in the **South China Sea** (such as the Spratly Islands) that are claimed by China, Malaysia, Vietnam and the Philippines.
- the dispute between **Peru and Chile** about where their boundaries should be drawn in the Pacific Ocean; this dispute involves control of tens of thousands of square kilometres of rich fishing territory.
- the dispute between Italy and Slovenia on one side and Croatia on the other over Croatia's proposal to establish the Ecological and Fisheries Protection Zone (ZERP) in the **Adriatic Sea**.

### Question Bank 3J

1. *What rights and responsibilities does a country possess when it has sovereignty over an area of ocean?*
2. *Explain the difference between sovereignty rights of countries within their territorial limits and exclusive economic zones (EEZs).*
3. *Figure 3.115 shows the extent of control over the world's oceans by countries that have coastlines. Who do you think controls the other ocean areas (shown in light blue)?*
4. *Choose a current (ongoing) geopolitical conflict over an ocean resource that is not fishing. Research the conflict and then suggest a realistic solution to the conflict.*

- 



**3.116** In this view of the Gulf of Aqaba, looking north, four countries are shown. In the west (left of the photo), the territory is the Sinai Peninsula of Egypt. At the head of the Gulf of Aqaba, Israel extends to the north. To the north-east of the head of the Gulf, the territory belongs to Jordan, while in the right foreground, extending to the east, the land belongs to Saudi Arabia. All four countries have some coastline on the Gulf of Aqaba, and so sovereignty of the waters is divided, being allocated to the country closest to the water in question.

# Chapter 4 Ocean management futures

4.1 Fishing boats line the beach at Cape Coast, a fishing port on the Gulf of Guinea coastline of Ghana.

## Biotic ocean resources

### The Resource Base

The world's oceans represent a valuable **resource** base for the planet. In addition to its role in regulating the earth's climate, the oceans provide many products that are useful for humans. Because accessing resources is more difficult in the deep oceans than in the shallow continental shelves, the **margins of the oceans** tend to have the greatest demands placed upon them to provide resources for humans. However, as technology develops and cost structures change, even the deepest and remote ocean areas are seen as being able to provide resources for human use.

### Fishing and whaling

Perhaps the most obvious biotic resource that the ocean provides for humans is **fish** — certainly fishing has a history of thousands of years. Today, fish supply 16% of the world's protein to humans, and the annual fish catch is more than 90 million tonnes world-wide.

**Fishing** is conducted at a **variety of scales**, from individual people casting nets to large trawlers that operate like highly mechanised factories. While most fish that are caught are used for human

4.2 A lone fisherman uses a net to catch fish using traditional methods that have been used for centuries at the edge of a coral reef in Nauru.

4.3 The Tofinu people make their living from fishing in Lake Nokoué, which is a large coastal lagoon near Cotonou, Benin. They fish by erecting vertical palm branches in the muddy bottom of the shallow lake, and these attract the fish as they start to decompose. Nets around the palms hold the fish until they are collected by fishing families in small boats.

4.4 Traditional shore-operated lift fishing nets in Cochin, India. Each net is about 10 metres high and 20 metres wide, and is lifted using large rocks as counterweights. In the background, an ocean-going fishing boat shows more modern technology.

consumption, some fish are used to feed animals or to provide oils as raw materials for industrial processes.

Traditional fishing methods were designed to obtain food for **subsistence** purposes. Even today, fishing within most poorer societies takes only the quantities of fish needed for food in the local community. Under these circumstances, fish remain a **renewable resource**.

This situation changes, however, with **commercial fishing**. In commercial fishing, there is an incentive to catch as many fish as possible to make as much money as possible. Under these circumstances, the fishing industry has great difficulty in conserving resources partly because fish can move across local and national boundaries, and **overfishing** can occur. Within any country there can be the enforcement of rules about the size of fish that can be taken and about the bag limit for individual fishers. Such rules are made to ensure that each species has fish reaching breeding age. These actions can help to **conserve** fish stock in estuaries and coastal waters wherever there are sufficient inspectors to police regulations. Of course, the destruction of breeding habitats may counteract such conservation measures.

Where ocean stocks are being considered, there is the problem that fish may **move** great distances during their life cycle, and this will mean crossing the boundaries of the controls imposed by any individual country. Territorial waters now extend some 370 kilometres from the shore, and this means there is an overlap between many countries, or at least dispute as to where the line should be placed. Many maritime countries accidentally or deliberately enter other countries' territorial waters and remove fish and other marine sources of food. Adequate **patrolling** can go some way to seeing that any conservation measures are observed. However, with **dwindling fish stock** there is pressure to move into parts of the ocean where intruders could argue they were unaware they had strayed over the border. In any case if they are taking undersized fish near an ocean border they are depleting breeding stock on both sides.

Much more efficient fishing techniques have been developed in recent years, including:

- **air surveillance** and various radar devices to locate fish schools;
- larger, faster, better equipped **factory ships** to process and preserve the catch; and
- **better netting techniques** that often require the team work of a number of fishing boats.

At the same time as these changes were occurring, the size of the world's **fishing fleets** grew. As a result of all this, fish can now be caught in quantities that **threaten** the **survival** of species. The **drift net** is still being used by fishers from some countries, despite being banned in international agreements. This type of large and almost invisible net snares virtually everything that is unlucky enough to swim into it, including unwanted as well as protected marine species.

4.5 Hundreds of fishing boats in the port of Elmina, Ghana, demonstrate the large number of fishing boats in coastal areas.

Where there are **special markets** for particular fish such as the tuna in Japan or coral trout and sharks (for shark fin soup) in Hong Kong, the price that fishers can obtain encourages them to take greater risks of breaching territorial waters. In some cases a country such as New Zealand can benefit from gearing its methods of fishing, storage and preparation of fish such as tuna to reap the profits if they feel the fish is not an endangered species in their waters. On the other hand, as the result of illegal fishing, a fish species such as the coral trout has been taken from the protected marine park of the Great Barrier Reef to appear later in Hong Kong restaurants.

**Shark fin soup** is a noteworthy example of the problem. Shark fin soup is a prestigious dining

4.6 Typical small fishing boats in Zanzibar, Tanzania. Fishing on this scale does not usually threaten fishing stocks by over-exploitation.

4.7 Medium-sized fishing boats in Heimaey, Iceland. Unless such boats operate in a concentrated manner, they can usually operate sustainably.

4.8 A large Russian 'factory' fishing vessel, which uses radar to search for dense schools of fish, is docked in Singapore. These ships operate globally and pose a significant risk of overfishing.

item in China, including Taiwan and Hong Kong, where it is traditionally served at important celebratory dinners. However, to obtain the fin needed for the soup, the shark is captured, their fin is removed, and the shark is then thrown back into the water to die. It is estimated that 100 million sharks are killed each year, 73 million of them for shark fin soup. Consequently, shark populations have dropped by about 90% in the seas off the coast of East Asia. As a result of **environmental lobbying**, the demand for shark fin soup is now declining a little in Hong Kong, though not in mainland China. Ultimately, the price that people are prepared to pay for fish (including sharks) influences whether conservation is likely to be successful or not.

The three **big questions** that face **management** of the ocean's fishing are these:

1. What is the carrying capacity of the world's oceans?
2. How many fish are there in the oceans, and how many of each type of fish should be caught to ensure the world's fishing industry is sustainable?
3. How should the world's fishing resources be divided among the world's people?

Overall, **conservation measures** to preserve fish numbers are having only a minor impact. The trend in marine fish catches has been downwards since about 1970 in spite of greater success in catching the fish that are found in the seas. This indicates that the **types of fish** traditionally sought by the industry are probably over-exploited and are being replaced in catches with **different species**. Thus, the total catch is being maintained by some non-traditional species such as the sprat and pollock, which are smaller than the more popular fish. Ways of **marketing** small fish, such as canning and making of fish-meal, will continue. In this way, the protein yield from fish may be maintained for some years, but it will be by **species substitution**, not the result of active conservation of the better types of fish.

Another response to overfishing is imposing **quotas** on the size of fish catches. An example of an international fishing quota system is the **Common Fisheries Policy** (CFP) of the European Union. The CFP sets quotas for each species of fish, and each member country is allocated its TAC (**Total Allowable Catch**). The policy aims to match the supply of fish to the demand while also protecting endangered or sensitive species of fish.

A variation on quotas is setting restrictions on the number or size of **fishing vessels**. This is achieved by preventing vessels over a certain size from entering restricted areas, sometimes called **conservation areas**. A negative aspect of this approach is that some boat owners have modified their vessels to comply with the size restrictions, but this has made the vessel less seaworthy or less stable.

One alternative approach to ocean fishing, which is essentially a form of 'hunting', is to 'farm' or 'raise' fish in a contained area. This practice is known as **aquaculture**. Aquaculture is the breeding, rearing and harvesting of fish (and oysters, plants and other marine wildlife) in enclosed areas such as cages in ponds or enclosed areas of lakes, rivers or the ocean. As fish stocks are depleted in the world's seas, aquaculture is a potential way of increasing the supply of seafood while not overfishing the oceans.

4.9 Aquaculture does not require large capital investment. This simple fish farm is located on the edge of a coastal lagoon near Poothotta in Kerala, India.

One of the **challenges** of aquaculture is that it has always been conducted in accessible areas close to the coast or in coastal rivers and lakes. Coastal areas tend to be more polluted than the open ocean, and therefore the fish harvested from aquaculture tend to have higher levels of **toxins**. This has been a particular concern in densely populated areas such as China and Vietnam where coastal waters have high concentrations of chemicals and antibiotics. When marine organisms are raised in polluted waters, the pollutants build up and become more concentrated in the organism, increasing the health risk for humans who consume those organisms.

Catching **mammals** such as seals and whales is another form of exploiting the ocean's biotic resources. Hunting **seals** (sealing) is a long-standing practice among traditional societies in Arctic areas such as Greenland, Canada, the United States, Norway, Iceland, Russia and Finland. Although much of the world's seal hunting is small in scale, the extent of commercial sealing expanded in the late 20th century, causing concern that the resource was being over-exploited.

**Controversy** grew when videos were widely distributed showing cruelty to the seals, including clubbing seal pups to death in Canada. As a result of public outcry, restrictions on seal hunting in Canada were introduced, and demand for clothes made from fur plummeted.

**4.10** This is a daily scene in most towns in Greenland, such as Qaqortoq, shown here. Seal hunters skin and butcher their catch beside the water to sell the meat at nearby stalls to townsfolk. Seal meat is the main source of protein in this cold climate where it is too cold even to raise cattle. Although the seals are killed primarily for food, the furs are also used for clothing.

**4.11** Butchering seals in Narsaq, Greenland.

**Whaling** is the hunting of whales to use for meat, oil, blubber and scientific research. Although whaling has a long history that dates back thousands of years, it is a very **controversial** practice these days because of the industrial scale of its current practice.

In 1986, the International Whaling Commission **banned** commercial whaling in an effort to increase whale numbers, allowing limited numbers of whales (defined by **quotas**) to be killed for scientific research purposes. However, conservationists claim that the countries that still kill whales — Japan, Norway and Iceland — are pushing the restrictions beyond reasonable limits, making their whaling operations illegal.

Sea mammals such as whales and dolphins tend to evoke strong **emotional** feelings in many people, and therefore breaches of restrictions on whaling tend to receive more publicity than the steep reductions in the stocks of some of the world's most popular fish. Although Japan and Norway still do not recognise some international agreements, the numbers of most whale species have shown a steady **increase** in the last few decades. In many places, whales contribute significantly to **ecotourism** as people join whale-watching cruises.

## Question Bank 4A

1. *What are the factors that lead to overfishing?*
2. *What are the consequences of overfishing?*
3. *What alternative strategies are being implemented to address the issue of overfishing?*
4. *How do you think the biotic resources of the ocean (fish and mammals) could be managed more effectively?*

## CASE STUDY
## Management of fishing in Hong Kong

Like many coastal areas in southern China, fishing has been an important industry in Hong Kong for hundreds of years. An important part of the diet for people in southern China, fish provide both a source of **protein** and a major source of **income**.

**4.12** The typical coastal environment of Hong Kong — islands, inlets, and rocky shorelines — near Sai Kung.

**4.13** Tolo Harbour shows another view that is typical of Hong Kong's coastline. The structures in the water to the right of the photo are fish breeding rafts, a form of aquaculture known as 'mariculture'.

**Hong Kong** is located beside a wide continental shelf on a rocky coastline with many small inlets and bays, a large number of islands and many small rocky reefs. The waters are generally shallow, being between 10 and 20 metres deep. These circumstances combine to provide Hong Kong's waters with a rich variety of habitats in a relatively small area and thus a diverse and abundant supply of sea life.

Hong Kong's **fishing fleet** expanded greatly in the years following World War II, and its boats ventured well beyond Hong Kong's local waters. In Hong Kong's spirit of imposing very few government regulations on business activities, there have been very **few restrictions** on fishing operations both inside Hong Kong and in its surrounding waters. Regulations have essentially


**4.14** A waterside sign on the island of Tung Ping Chau outlines the restrictions on fishing in the area: no use of suction devices, no use of explosives, no use of dredging devices, no use of toxic substances, no use of electricity, and no use of trawling devices.

been limited to bans on the uses of explosives, poisons and some other destructive methods, as well as fishing bans in certain shipping channels, especially Victoria Harbour in the central business district of Hong Kong. Therefore, restrictions that forbid catching young fish, breeding fish and mature fish all together that apply in many parts of the world have never applied in Hong Kong.

It became obvious in the late 1980s that the number of fish in Hong Kong's waters was declining sharply. The **decline in fishing stocks** was due to four main factors:

- Government authorities have been focussed on increasing the **overall catch** and have paid little

**4.15** In Hong Kong, fish are farmed in cages suspended by floating rafts in sheltered coastal areas. There are more than 1,000 licensed operators in 26 designated fish culture zones that occupy more than 200 hectares of sea area. Mariculture produces 7% of all locally consumed fish in Hong Kong.

attention to either the health or **sustainability** of the industry.

- Until recently, **statistics** collected by the Government did not separate catches made solely within Hong Kong's waters and those made elsewhere, and this hid the declining trend of fishing within local waters.
- The basis of collecting government statistics had been **inconsistent** from year to year, also making trends difficult to discern.
- Hong Kong's waters had been impacted by a variety of factors that **lowered the yields** from fishing, including water pollution, large-scale reclamation, dredging and dumping operations, all of which disturbed or destroyed habitats in many areas.

The decline in fishing production continues today. One explanation is the expansion of Hong Kong's **fishing fleet**, which now numbers about 3,700 fishing vessels. Most of these are sampans and small fishing boats, but 1,100 of this number are large commercial trawlers. The growth of commercial fishing meant that by the mid-1990s the average size of fish caught by trawlers was less than 10 grams with an average length of about 10 centimetres. At about the same time, a government study found that 12 of the 17 fish species examined were heavily over-exploited, while the remaining five were fully exploited. In 2006 another government report found that the annual Hong Kong fishing catch of 26,700 tonnes was 30% higher than the maximum sustainable annual yield of 20,500 tonnes.

The first step towards developing a **conservation policy** for fishing in Hong Kong occurred in 1995 when the government introduced the Marine Parks Ordinance.

Under the Ordinance, **four Marine Parks** were declared in 1996, these being Hoi Ha Wan, Yan Chau Tong, Sha Chau and Lung Kwu Chau, together with one Marine Reserve, Cape d'Aguilar. Another Marine Park, Tung Ping Chau, was designated five years later in 2001.

Within the Marine Park areas, commercial fishing was permitted provided only small-scale equipment was used. The restrictions were a little tighter within Tung Ping Chau Marine Park where

4.16 Signs in the Tung Ping Chau Marine Park regulate fishing activities.

all commercial fishing was banned. It is important to remember that these Marine Protected Areas were not intended to restore the number of fish for catching; Marine Parks were intended for the **conservation** of marine life and habitats and to encourage recreation, while the Marine Reserves were intended to encourage scientific study in areas where there would be minimal human disturbance.

Statistics suggest that the introduction of the Marine Parks and Marine Reserves were having very **little effect** on increasing numbers of fish. One possible reason for this is that the Marine Protected Areas are all quite small in size, the most extreme example being the Cape d'Aguilar Marine Reserve which covers an area of only 18 hectares and which in several areas is less than 10 metres wide. Another factor could be that the regulations are not strongly enforced.

4.17 A trawler using nets in the waters of Tolo Harbour before the ban on such activities began in 2013.

In a further effort to make Hong Kong's fishing industry more sustainable, the Executive Council imposed a **ban on trawling activities** within Hong Kong's waters from the beginning of 2013. The ban on trawling in Hong Kong was expected to reduce the annual local fish catch by 40%.

Before it was banned, trawling was the most **intensive** type of fishing conducted on the sand and mud sea-bed of the continental shelf, including within Hong Kong's waters. Under this system, one or more heavily-weighted nets were dragged over the sea-bed by fishing boats to harvest shrimps, fishes, crabs and other edible species. As the nets were dragged at quite high speed, and the mesh size of the net was small, bottom trawling was **indiscriminant** in what it caught. The practice was like a bulldozer scraping the sea bed, and thus extremely destructive to sensitive and fragile sea-bed communities such as sponges, sea-fans, and soft corals. For every kilogram of fish that went to market, between 10 and 100 kilograms of non-commercial species were killed in the process and simply thrown away as bycatch.

Continuing concerns about dwindling fish stocks led the Hong Kong Government to commission several **expert studies** to investigate strategies for improving the situation. As a result of the investigations, six recommendations were made to the Government, these being:

- establish a fishing licence program;
- limit new entrants to the fishing industry to reduce fishing pressure;
- enhance habitat;
- restore habitat;
- conduct fish re-stocking trials; and
- establish nursery and spawning ground protection areas (Fisheries Protection Areas, Marine Parks and Reserves.

Of these recommendations, the Government accepted only two, which were to enhance habitat (by starting an Artificial Reef Program) and to conduct fish re-stocking trials.

The objectives of the **artificial reef program** were four-fold:

- to enhance marine resources;
- to rehabilitate degraded habitats;
- to protect spawning and nursery grounds; and
- to enhance habitat quality in open sea-bed areas.

**4.18** Seafood is very popular in Hong Kong, leading to a constant and strong demand. These fish are for sale (for eating) in an open-air restaurant Sai Kung, a fishing village in eastern Hong Kong.

**4.19** Fresh fish being sold to consumers directly from fishers' boats beside the wharf in Sai Kung, Hong Kong.

In Hong Kong, artificial reefs have been built using old tyres, concrete cylinders, sunken ships and metal chains. They serve as **breeding refuges** for fish, and as such they are off limits to fishing activities.

There is some dispute about the **effectiveness** of the artificial reefs. Over 200 fish species have been identified and recorded on the reefs, but researchers disagree as to whether they have been attracted away from nearby natural reefs, or whether they exist solely as the result of the additional habitat provided by the artificial reefs. In Hong Kong, this is sometimes known as the '**aggregation vs enhancement**' debate.

In 2004, a **fishing licence scheme** was introduced in which all ships involved in commercial fishing would require a fishing licence. This has been a successful measure to regulate the number of ships harvesting fish at any one time. However, the scheme does not include recreational fishing, and conservation organisations such as the WWF (World Wildlife Fund) have been pushing to have the scheme widened to include such vessels.

Since 1999, China has enforced an annual '**closed season**' policy towards fishing in the South China Sea. This has been intended to give fish time to reproduce without being disturbed by fishers in the hope that fishing stocks will increase in numbers as a consequence. The closed season takes place each June and July and covers the main reproductive season for marine life in the region. Although the 'closed season' restrictions do not apply in Hong Kong waters, it does apply to Hong Kong ships that fish outside local waters in the South China Sea. Reports suggest that the 'closed season' management strategy has been successful in increasing both the numbers of fish and the biodiversity in the region's oceans.

### Question Bank 4B

1. *Explain why the number of fish in Hong Kong's waters has been declining.*
2. *Describe the elements of Hong Kong's fishing conservation policies and comment on the effectiveness of each element.*
3. *In what ways can (and should) Hong Kong's approach towards fish conservation be applied elsewhere?*

## Abiotic ocean resources

The world's oceans are increasingly being used as a source for **minerals** and other **abiotic** resources such as oil and gas.

About **one-third** of the planet's oil and gas comes from the world's oceans and seas. This figure is likely to **rise** in the years ahead as easy-to-obtain oil and gas reserves on land and shallow water areas become exhausted, driving exploration to deeper ocean areas.

The **largest offshore** reserves are found in the shallow waters of the **Persian Gulf**, whose waters are shared by Iran, Kuwait, Saudi Arabia, Qatar, Bahrain, Oman and the United Arab Emirates. The Persian Gulf currently produces about 28% of the world's oil, and it contains approximately 55% of the world's crude oil reserves. Gas is often found in areas containing oil, and the Persian Gulf is a good example, as it produces 18% of the world's natural gas and holds over 40% of total reserves.

The techniques of offshore oil and gas exploration were pioneered during 1940s in the northern section of the **Gulf of Mexico**, south of the Texas and Louisiana coastlines in the United States. The region continues to be an important producer of oil and gas, although for strategic reasons, very little is exported; it is almost all used for domestic US consumption.

4.20 Offshore oil drilling requires a huge capital investment, as shown by this huge drilling rig which is under repair in dry dock at the BP Logistics and Operations Base on the shores of the oil-rich Caspian Sea near Baku, Azerbaijan.

Since the mid-1960s, the **North Sea** has become a significant area of oil and gas production. The oil reserves of the North Sea are split between the countries bordering the area according to their EEZs — mainly Norway and the United Kingdom, with minor oil reserves also falling into the areas controlled by Denmark, Germany and the Netherlands.

Other significant areas of offshore oil and gas exploration include the Caspian Sea (off the coast of Azerbaijan), coastal West Africa (off the coasts of Nigeria and Angola), the South China Sea (a disputed zone) and the Russian Far East (off the coast of Sakhalin Island).

In general, it is much more **difficult** and therefore more **expensive** to obtain resources from the oceans than the land. Drilling for oil or gas in the sea floor is technically difficult, especially when the water is deep and the climate is harsh as conditions often are in the North Sea. The technical challenges are significant, and the financial investment required is huge. Nonetheless, if the resource is sufficiently **valuable** then the profits may be sufficient to justify the high costs.

In addition to oil and gas, the oceans are a source for many valuable **minerals**. Important minerals include gold, silver, manganese and diamonds. Because of the difficulty of obtaining these minerals from undersea locations, the quality must be high to justify the high costs.

Unfortunately, mining in the oceans often causes so much devastation that the **natural ecosystem**s are destroyed. For example, when **dredging** is used to bring materials from the sea bottom to the surface, the ocean floor is totally destroyed, wiping out all marine habitats including fish, invertebrates and breeding grounds.

Oil extraction poses special problems because the consequences of **spillages** are so serious. A serious incident occurred in the Gulf of Mexico in April 2010 when an oil rig, the **'Deepwater Horizon'**, exploded, caught fire, capsized and sank, releasing a gusher of oil into the Gulf of Mexico waters that flowed for 87 days. It was estimated that 4.9 million barrels of oil (the equivalent of 780,000 cubic metres) were spilt, which formed a slick that spread across the water, killing marine life and polluting the shoreline areas of the Gulf. In an effort to clean up the oil spill, 6.8 million litres of dispersants were pumped into the Gulf of Mexico to emulsify the oil and allow bacteria to metabolise it. The company that was held to be responsible, BP, was ordered to pay over $US60 billion in fines.

**4.21** Fire boat response crews battle the blazing remnants of the off shore oil rig 'Deepwater Horizon'.

**4.22** An oil-drenched pelican lies on a Gulf of Mexico beach that has been covered in oil from the 'Deepwater Horizon' accident.

**4.23** An oblique aerial view of salt evaporation flats on the west coast of North Korea near Sukchon, north-west of Pyongyang.

**4.24** A large stockpile of salt harvested from the evaporation ponds of the Riotinto Dampier Salt Works, Port Hedland, Australia.

Oil spills are not the only risk to the oceans from offshore drilling. Fish and marine mammals are threatened by **seismic surveys**, discharges of **drilling fluids**, **methane emissions** from gas flaring, and other consequences of the drilling process. At present, there are no internationally accepted rules to govern this potentially hazardous activity.

Not all the abiotic resources obtained from the sea are expensive or environmentally hazardous. **Salt** is obtained by **evaporating seawater** in evaporation ponds (also known as salterns or salt pans) in many countries. Seawater is pumped into the ponds, and after the water has evaporated, the salt deposits that are left behind are harvested. Salt evaporation ponds work best in hot, dry areas, and large areas of salt evaporation ponds are found in Israel, Jordan, Thailand, Slovenia, Australia and North Korea, among other locations.

Global standards have been established to try and protect the world's oceans from pollution and waste. The **United Nations Convention on the Law of the Sea** (**UNCLOS**) was signed in 1982 and came into effect in 1992 to establish general guidelines for the management of marine resources. Although 167 countries, plus the European Union, have signed UNCLOS, it lacks mechanisms to enforce the regulations when they are violated. Furthermore, several countries, including the United States have not ratified the treaty, which means they are not legally bound to its principles.

### Question Bank 4C

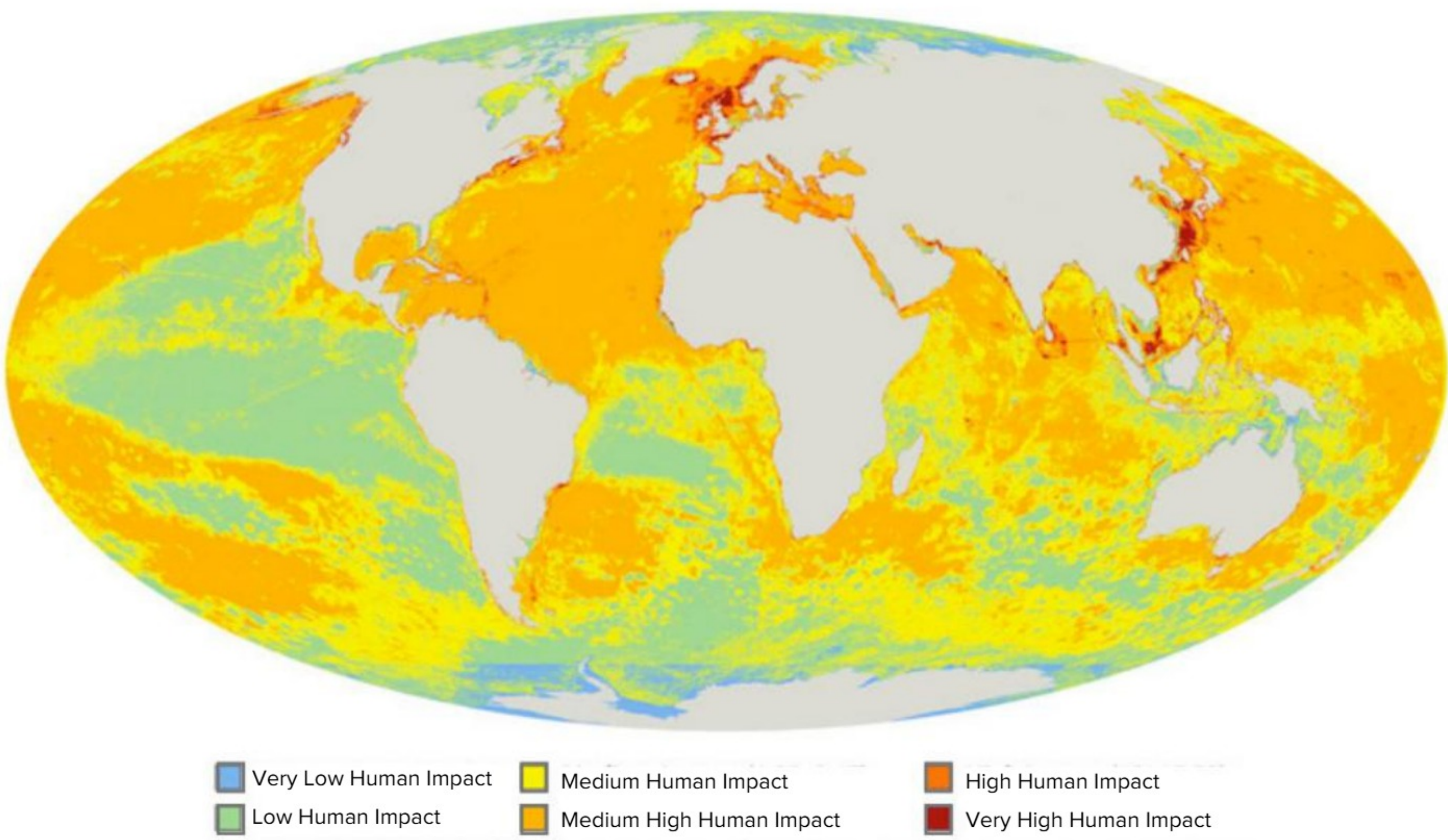
1. *What is causing the increased demand for the abiotic resources of oceans?*
2. *What are the consequences of this increased demand for the abiotic resources of oceans?*

# Managing ocean pollution

## Waste

**Pollution** in oceans is a major problem in all parts of the world that has negative impacts on marine life and therefore indirectly, on humans. **Oil spills**, **toxic wastes**, **dumping garbage** and **sewage**, along with **agricultural wastes**, **dirty water** and other **harmful substances** are all significant sources of pollution in the oceans.

The National Centre for Ecological Analysis and Synthesis has produced a detailed map showing the impact of humans on marine ecosystems in all the world's oceans (figure 4.25). The map combines the impacts of six different types of **fishing**, **inorganic pollution**, **invasive species**, **nutrient input**, **acidification**, the impact of **oil rigs**, **organic**




4.25 Human impact on the world's marine ecosystems. Source: National Centre for Ecological Analysis and Synthesis.

**pollution**, **population pressure**, the impact of **commercial shipping** and two aspects of **climate change** (sea surface temperatures and ultraviolet impacts. This information was combined with our current understandings of the vulnerability of different marine ecosystems to pollutants and other forms of human impact.

The data in the map shows that the most **heavily impacted** ocean areas are the North Sea, the South and East China Seas, and the Bering Sea. Many of the coastal areas of Europe, North America, the Caribbean, China and Southeast Asia are also heavily affected by human impacts.

On the other hand, the areas that are **least impacted** by humans are mainly near the poles, but other less impacted zones are found along the northern coast of Australia, and in small, scattered places along the coasts of South America, Africa, Indonesia and in the tropical Pacific. Not surprisingly, oceans which are further away from areas of dense human settlement and away from major shipping lanes are likely to be the least impacted areas.

The information in figure 4.25 provides useful insights into the sources of pollution that make the most significant impact on the oceans. For example, there are some activities that have little impact on the oceans, while other more harmful activities perhaps need to cease or be relocated to less sensitive areas.

Particular problems arise in places where **sewage pipes** share tunnels with storm water drains. When heavy rainfall occurs, the contents of the sewage pipes may overflow and the sewage waste becomes mixed with household wastes and storm water runoff, which then flows into the ocean. In many parts of the world, sewage flows untreated (or inadequately treated) into the ocean, and as an example, it has been estimated that 80% of the human sewage discharged into the Mediterranean Sea is untreated. Like fertiliser wastes, sewage can lead to eutrophication as well as spreading infectious diseases.

Poisonous materials that are dumped into the oceans are known as **toxic wastes**, and they are probably the most harmful form of pollution both for aquatic life and humans. When toxic waste harms an organism, the damage usually becomes

4.26 This communal toilet in Riwo village, on the northern coast of Papua New Guinea, disposes untreated sewage directly into the ocean below.

**magnified** as it quickly passes through the food chain, sometimes finishing as seafood consumed by humans. In any **food chain**, smaller organisms are consumed by larger organisms, and as this process continues the concentration of any pollutants increases, hence the risk to humans from eating contaminated seafood. Toxic wastes enter the oceans from various sources such as discharges from ships, and leakage from landfills, dumps, mines, and farms. Toxic chemicals from farm wastes and heavy metals from factory wastes have especially serious impact on marine life.

**Farm wastes** are a serious form of ocean pollution. When pesticides and fertilisers are used, the excess quantities flow through rivers and into the oceans. Runoff containing fertilisers bring extra nutrients into the ocean, and these can cause **eutrophication**, which is an excessive richness of nutrients in a body of water which causes a dense growth of algae and other plant life, which in turn depletes the available oxygen supply, thus causing the suffocation of other marine life. Eutrophication has created enormous '**dead zones**' in several parts of the world, including the Gulf of Mexico, parts of the Mediterranean Sea and the Baltic Sea.

Toxic wastes may have a devastating impact on **fishing industries**. One particularly dangerous toxic chemical in oceans is **lead** as it can cause serious health problems such as damage to the brain, kidneys, and reproductive organs. Lead has been found to cause birth defects, both in marine organisms and in humans, as well as birth defects, nerve damage, lowering IQ scores, stunting growth, and causing hearing problems in children. The main sources of lead pollution are wastes from paint, lead batteries, fishing lures and water pipes.

**Boats** and **shipping** are very significant causes of pollution. The main types of pollution from boats are waste oil and other petrochemical fuels, but garbage is also often dumped from boats directly into the oceans, adding a variety of organic and inorganic wastes. Although oil spills can be catastrophic when they occur, and they receive a great deal of publicity, they are only responsible for about 12% of the oil entering the oceans each year. According to a study by the US National Research Council, 36% of the oil entering the oceans does so by flowing through drains and rivers as waste and runoff from cities and industry.

**4.27** An oil slick on the water smothers other rubbish floating in the water with oil in the harbour of Havana Bay, Cuba.

A significant **initiative** to reduce oil spills is being implemented around the world with a **ban** on single-hulled tankers. From 2010 in Europe, 2011 in South Korea and 2015 in the United States, all tankers must be **double-hulled**, which reduces the risk of accidental punctures in the hull that would result in an oil spill.

Another initiative to reduce the environmental impact of ships on ocean waters include a recent ban on the use of **tributyltin**, a cheap chemical that was used in paints on boat hulls to reduce the growth of organisms such as barnacles and algae. Tributyltin was found to poison a wide range of organisms at the base of the food chain, so its toxic impact was magnified in organisms further up the food chain such as fish and mammals, and even humans who consumed affected fish.

**4.28** Beachgoers seem to enjoy their time at the seaside in spite of the thick slick of oil that covers the sand on this small beach near the container wharves in Colombo, Sri Lanka.

Another environmental issue caused by ships is the impact of **ballast water**. Most big ships use large quantities of water for ballast, taking in water at one port and discharging it at another. When the ballast water is discharged, it usually contains biological materials, including weeds, marine life, bacteria and viruses. Introducing alien species can damage local ecosystems, so measures are being considered to require **filtration** or **treatment** of ballast water.

About 80% of all ocean pollution comes from **land-based activities**. Human wastes that are dumped in oceans directly from the shore include household garbage, factory wastes, sewage, waste water from bathing and plastics. Most types of garbage that are dumped into the oceans takes a long while to break down, and this is especially so for plastics and radioactive wastes.

Some types of rubbish cause special problems in marine habitats, such as **plastic bags**, which can be mistaken for food by many marine organisms. Currently the mass of plastic in the world's oceans is equivalent to 20% of the weight of all the world's fish, and it is predicted that the weight of plastic in the ocean will be the same as the weight of all the fish in the ocean by 2050. Fish are attracted to plastic bags and may become entangled in them, or the bags may block the breathing passages and stomachs of species such as whales, dolphins, seals and turtles, causing death by suffocation.

Most of the plastic in the world's oceans is not, however, the result of plastic bags and bottles, but **microplastics**. Microplastics are minute beads,


**4.29** "Plastic bags kill" is the message on this large billboard beside the highway at a local petrol station near Tchaourou, Benin.

fibres and fragments of plastic that measure two millimetres in diameter or less. Microplastics are somewhat like a marine form of smog, making the waters cloudy and coating the ocean floor. Microplastics also resemble food to many organisms that suffer when they ingest it.

From 2016, the United States banned microbeads, which are a form of microplastic. **Microbeads** are minute plastic particles that scrub teeth when they are cleaned. Microbeads get flushed into the oceans, adding to their pollution. They are still used extensively outside the United States.

**4.30** Plastic wastes leach chemicals into the coastal waters in Paramaribo, Suriname.

Between 1946 and 1993, more than a dozen countries used the oceans to dump **nuclear wastes**. The solid and liquid radioactive wastes were the by-products of using nuclear fuels to generate electricity, and were placed in designated zones in the Arctic, Atlantic and Pacific Oceans in specially sealed containers. Critics worry that an **accident** or **decay** of the containers might release the toxic nuclear materials into the ocean's circulation.

The overwhelming majority of the nuclear materials were dumped by the USSR and the UK, but significant quantities were also dumped by Switzerland (even though it has no coastline), the United States, Belgium, France and the Netherlands. Since 1993, the dumping of radioactive wastes in the sea has been **banned** under several international treaties. However, nuclear waste remains toxic for many decades, so the threat posed by radioactive wastes will continue well into the future.

### Question Bank 4D

1. *Describe the sources and distribution of pollution in the oceans.*
2. *What are the implications of the pollution of oceans by the disposal of toxic materials such as oil and chemical waste?*
3. *Which of the types of pollution discussed in this section worries you the most? Give reasons to explain your answer.*
4. *Outline the strengths and weaknesses of initiatives to manage ocean pollution, including local and global strategies for radioactive materials, oil and plastic waste.*

## The strategic value of oceans

As the world has become more globalised and the international economic situation seems to have become more competitive, the world's oceans have attracted greater attention. Biotic and abiotic resources in the oceans are viewed as **potential assets** by governments and companies in many countries, and the oceans themselves are viewed strategically by geopolitical analysts who are interested in the movement of ships and cargo around the world.

Ever since the earliest days of military operations in ancient Egypt, China, Greece and Rome, the oceans have had **strategic** importance. Navies have used the oceans for both **movements** to faraway places and **operations**, such as invasions and territorial gains. Navies can operate freely in international waters, but they require the permission of the governing country if they wish to enter territorial waters that are not their own. **Ports** that are used

4.31 The port city of Vladivostok is the home base of the Russian Navy's Pacific Fleet. To protect its secrecy, the entire city was closed to foreigners during the Soviet era.

4.32 This concrete-faced tunnel in the cliff south of Dhërmi in Albania was a shelter for Soviet submarines in the 1950s. When relations deteriorated between Albania and the USSR in the early 1960s, the Soviets withdrew but left the submarines for the Albanians to use. This once secret site no longer has strategic importance, but is evidence of military use of the oceans.

by military forces have a high strategic value, and access is usually restricted to outsiders in an effort to protect military secrets and details of shipping movements.

Oceans and seas have always been the focus of territorial disputes between nations which is why territorial waters and EEZs have been defined. The shift to a world economy in recent decades has brought international ocean areas (the high seas) into a sharper geopolitical focus.

Although it is clear by definition which country owns the resources within its own territorial waters and EEZs, the question of who owns resources in **international waters** is not as clear. The **International Seabed Authority** (ISA) was established in 1994 to address this issue. The ISA is an intergovernmental organization that was established to organise, regulate and control all mineral-related activities in the international seabed area beyond the limits of national jurisdiction (i.e. in international waters). Based in Jamaica, the ISA has 167 member countries plus the European Union, but like the UNCLOS, it has not been ratified by the United States. This is a major weakness because the United States is one of the world's most significant maritime nations.

The ISA does not allocate ownership of resources in international waters, but it **awards licences** to explore. Its protocol is to establish regulations for the exploitation of mineral resources on the assumption that the company that has been awarded the exploration licence may subsequently exploit and own the resource. Protocols have been published on mining resources such as manganese nodules, which are found in deep areas of the central Pacific Ocean, sulphides, which are located around hot volcanic springs in the western Pacific Ocean, and ferromanganese crusts, which are mainly found along mid-oceanic ridges. The ISA has also been working to establish protocols for exploiting seabed waters in the Arctic Ocean, which is bordered by the competing interests of Russia, the United States, Canada, Norway, Iceland and Greenland.

Because EEZs extend some 370 kilometres from the shore of a country's coastline, some governments believe that exercising sovereignty over **remote islands** in the ocean is desirable if they suspect resources may be found in nearby waters. There are currently many territorial disputes between countries over islands and coastal areas, many of which are motivated by gaining resources. Examples of significant disputes include:

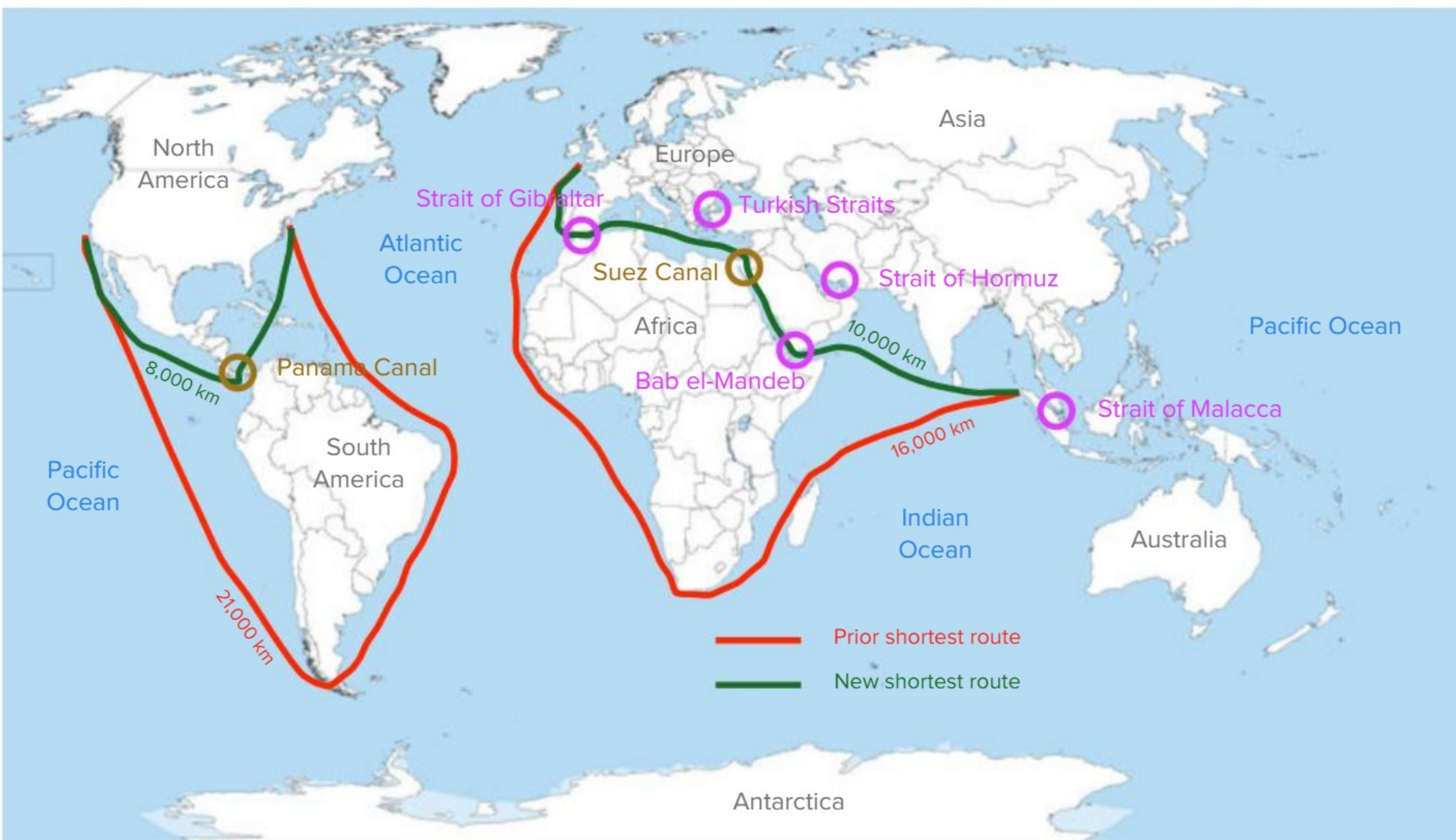
- The **South Kuril Islands**, which have rich fishing grounds and reserves of several minerals, are disputed between Russia and Japan;
- The **Khuriya Muriya Islands** in the oil-rich Persian Gulf are disputed between Yemen and Oman;
- The **Lioncourt Rocks**, which are located in the Sea of Japan (also known as the East Sea in Korea) have suspected large deposits of natural

gas, and are disputed between South Korea (supported by North Korea) and Japan;

- The **Minerva Reefs** are covered by water at high tide, leading Fiji to dispute Tonga's claim to the reefs and their surrounding waters;
- The 130 small coral reefs of the **Paracel Islands** (also known as Xisha in Chinese and Hoàng Sa in Vietnamese) in the South China Sea are disputed between China, Taiwan and Vietnam;
- The **Spratly Islands** in the South China Sea are claimed in whole or part by China, Taiwan, Vietnam, Philippines, Malaysia and Brunei. The Spratlys comprise 14 islands and more than 100 reefs in an area of strategic importance for shipping, with significant fishing grounds as well as oil and natural gas reserves;
- The continental shelf in the eastern **Gulf of Mexico** beyond the 370 kilometre EEZ is claimed by Mexico, Cuba and the United States;
- The **Falkland Islands** (also known as Islas Malvinas in Spanish) in a strategically important area of the Southern Atlantic Ocean are disputed between the United Kingdom and Argentina.

There are several points on the world's oceans where shipping routes pass through **narrow passages** that are vulnerable to disruption or attack. As shown in figure 4.33, these **transit chokepoints** include:

- the **Strait of Gibraltar** between Spain and Morocco, where the Mediterranean Sea opens to the Atlantic Ocean;
- the **Strait of Hormuz** between Iran and Oman joins the Persian Gulf and the Gulf of Oman; 35% of the world's petroleum traded by sea passes through this strait;
- **Bab el-Mandeb** between Yemen on one side, and Somalia and Djibouti on the other, connects the Red Sea and the Gulf of Aden; and
- the **Strait of Malacca** between Indonesia and Malaysia joins the important port of Singapore to the Indian Ocean.
- the **Turkish Straits**, which comprises the Bosphorus (which divides Europe from Asia at Istanbul, Turkey), and the Dardenelles to the south. The Turkish Straits connect the Black Sea with the Aegean Sea (and the Mediterranean).




**4.33** Strategically important transit chokepoints (purple circles) and ocean canals (brown circles). The red and green lines show the relative distances of shipping routes before and after construction of the Suez and Panama Canals.

Because of their strategic location and significance to world shipping, several of these narrow passages experience problems with **piracy**. Piracy is a recurring issue in the Strait of Malacca and Bab el-Mandeb, while the Strait of Hormuz is subject to periodic threats by Iran to close the passageway for political reasons.

Whereas the narrow passages listed above are all natural, two strategically important shipping lanes were **constructed**, these being the Suez Canal and the Panama Canal.

The 193 kilometre long **Suez Canal** was opened in 1869, connecting the Mediterranean Sea to the Red Sea through the Isthmus of Suez in eastern Egypt. The Suez Canal cut 16,000 kilometres off the traditional 16,000 kilometre long shipping route from Singapore that sailed past the Cape of Good Hope, which is the southern tip of Africa.

4.34 An oblique aerial view of the southern end of the Suez Canal, Egypt. Several ships are anchored in the Gulf of Suez (in the foreground) waiting their turn to enter the canal.

The **Panama Canal** was opened to shipping in 1914, joining the Pacific Ocean to the Caribbean Sea and the Atlantic Ocean through the Isthmus of Panama. Although shorter than the Suez Canal at 77 kilometres, the Panama Canal was arguably a more impressive engineering feat because it had to transit higher and hillier terrain. Construction of the Panama Canal reduced the traditional 21,000 kilometre shipping route from New York to San Francisco by 13,000 kilometres, eliminating the need to sail around Cape Horn, the southern tip of South America.

Shipping companies must pay **high fees** to use both the Suez Canal and the Panama Canal. The

4.35 A bulk oil tanker enters the Miraflores Locks at the southern (Pacific Ocean) end of the Panama Canal.

average toll to pass through the Panama Canal is $US54,000, while the average toll to pass through the Suez Canal is $US251,000. These high costs are more than offset by the savings in fuel, wages, maintenance and time that result from the shorter trips, making the canals economically viable for the shipping companies.

## CASE STUDY
## A contested ocean area - the South China Sea

The South China Sea is part of the Pacific Ocean that is situated east of Vietnam, west of the Philippines, north of Malaysia and south of China. It has an area of about 3.5 million square kilometres and is an important area for **international shipping**, with about one-third of the world's shipping passing through it. It is also estimated that **oil and gas** reserves measuring 28 billion barrels (4.5 cubic kilometres) lie under the South China Sea. The **fish** stocks have been severely depleted by many years of overfishing.

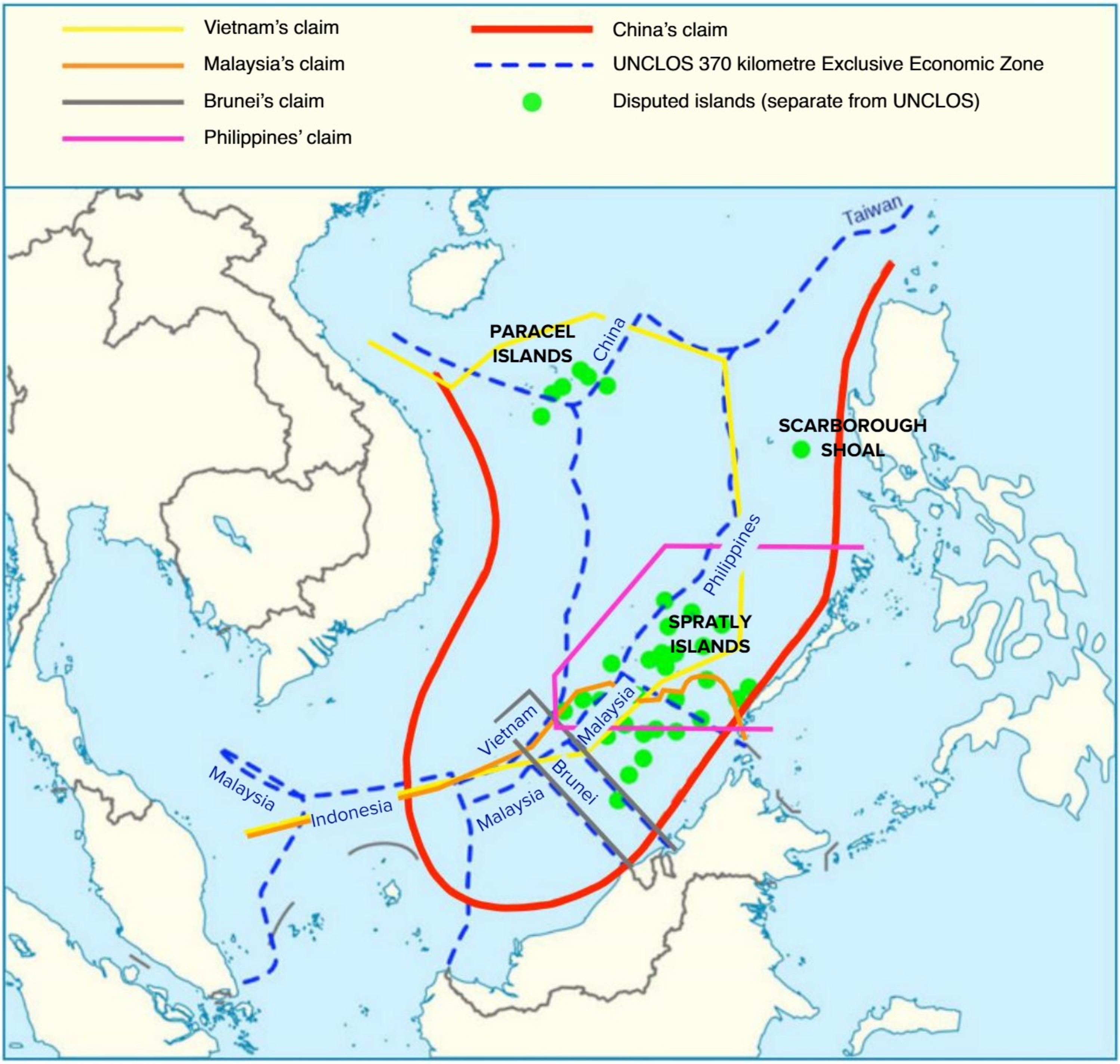
There are a few hundred islands in the South China Sea, most of which are tiny uninhabited rocky outcrops, reefs or sandbars. These **tiny islands** become significant when territorial claims are made by the countries surrounding the South China Sea, as several countries argue that their 370 kilometre EEZs should be based on these tiny islands.

The **three main groups** of islands are the Spratly Islands, the Paracel Islands and the Scarborough Shoal (figure 4.36). The largest group is the Spratlys, which has 175 islands, rocks and reefs in an area that measures 810 by 900 kilometres. The largest island in the Spratlys is 1.3 kilometres long and rises to an elevation of 3.8 metres above sea level. The Spratlys also has a submerged coral reef measuring 100 kilometres wide at a depth of 20 metres that has been underwater since the Holocene rise in sea level about 7,000 years ago.

As shown in figure 4.36, several of the countries surrounding the South China Sea have made territorial claims that extend beyond their EEZs and overlap with the claims made by other countries.

The **competing claims** are difficult to reconcile for three reasons:

- Some of the countries (China and Vietnam) have their **own laws** to define their 370-kilometre Exclusive Economic Zones (EEZs) that differ from the United Nations Convention on the Law of the Sea (UNCLOS);
- The UNCLOS framework does not contain any framework to **resolve disputes** about overlapping EEZs; and




4.36 The South China, showing the three main groups of disputed island groups (in green), the UNCLOS 370 kilometre EEZs (dashed blue) and the competing sovereignty claims made by China, Vietnam, Malaysia, Brunei and the Philippines.


**4.37** Chinese reclamation of Firey Cross Reef in the Spratly Islands, August 2014 to September 2015.

- The different types of outcrops in the South China Sea (islands, reefs and rocks) have **different legal rights**, and there is a different legal status again for the many tidal islands that are exposed at low tide and submerged at high tide.

The competing territorial claims have a **long history**. China's sovereignty claims are based on ancient control over the South China Sea that dates back to old dynasties such as the Han (206-220AD), Tang (618-906AD), Song (960-1279AD) and Ming (1368-1644AD). Throughout the second half of the 20th century, maps published within China invariably included the South China Sea as an integral part of China.

China's **motives** today include several factors:

- China sees sovereignty over the South China Sea as its **historic right**, and is thus a matter of national sovereignty and territorial integrity;
- with its rapid economic development, China is keen to safeguard its progress by having access to **energy resources** such as oil and gas; and
- China feels it needs to guarantee its **shipping access** to the Strait of Malacca; it is more confident this can be done if the South China Sea has a Chinese military presence rather than relinquishing control to the Vietnamese or allowing the United States to dominate the area, which China feels would happen if the South China Sea were to be declared international waters.

In recent years, the disputes over sovereignty in the South China Sea have **escalated**. China has been more assertive in arguing for its rights, while the United States has been increasingly vocal in declaring its rights of freedom of navigation through the South China Sea as international waters. The United States has been encouraging other countries in the region such as Japan and Australia to support its moves to limit China's control. Meanwhile, in 2009 China began enforcing annual **fishing bans** in the waters of the South China Sea, and backed these up with regular **patrols**, scientific **research** and military **exercises**. The Chinese patrols led to a clash with Vietnamese patrol boats in 2011 that attracted widespread attention internationally.

**4.38** Satellite views of Vietnamese reclamation of a sand island in the South China Sea from 2011 (left) to 2015 (right).

Following this incident, Vietnam's National Assembly passed a law in 2012 redefining Vietnam's sea borders to include the Spratly and Paracel Islands. The Chinese responded the same month by declaring the Spratlys and Paracels as part of a new prefecture-level Chinese city named Sansha.

**4.39** Chinese dredgers pump sediment onto Mischief Reef in the Spratly Islands to expand the land area.

In 2013 and 2014, China began an extensive program of **land reclamation** around some islands in the Spratly group, building civilian infrastructure such as ports, multi-storey buildings, radar facilities, helipads and airfields. By mid-2015, China had built seven artificial islands in the Spratlys amounting to an area of over 800 hectares. Construction of the artificial islands involves extensive **dredging**, which devastates the marine environment, especially the coral reefs. The dredging stirs up sand and silt that kills bottom-dwelling organisms when it re-settles, and it clogs the gills of most fish. Satellite images have shown long white strands of mucus emitted by millions of dying corals that were smothered by sediment.

In response to the reclamation, the President of the Philippines visited Japan and obtained assurances that Japan would provide its 'utmost support' for the Philippines, and the two countries conducted joint naval exercises in the South China Sea shortly afterwards. The United States has been supportive of Japan and the Philippines as it views China warily as an emerging rival power. In response, the Chinese Government sees the United States as an outsider with no legitimate interest in territory that the Chinese consider to be Chinese, making the US a threat to China's national security.

After the Chinese Navy seized control of Scarborough Shoal in 2013, the Philippines filed a complaint about China's territorial claims with the Permanent Court of Arbitration in The Hague. In July 2016 the tribunal ruled that China had **no legal basis** to claim historic rights over most of the South China Sea. It also ruled that land reclamation did not give EEZ rights, adding that China's reclamation work had caused severe ecological damage. China boycotted the hearing, and after the verdict was given, announced that it did not accept the findings as the tribunal had no legitimacy.

## Question Bank 4E

1. *Explain why oceans have strategic value.*
2. *What is the function of the International Seabed Authority?*
3. *How effective is the International Seabed Authority in resolving disputes? Explain why.*
4. *Looking at the list of significant examples of contested ownership of ocean or coastal territory, what seem to be the main reasons for disputes to occur?*
5. *In what ways do transit chokepoints pose strategic risks?*
6. *What are the advantages and disadvantages of using the Suez and Panama Canals for ocean shipping?*
7. *In what way is the South China Sea significant from a geopolitical or strategic viewpoint?*
8. *Which countries make territorial claims over areas of the South China Sea, and what are their motives?*
9. *Explain why the competing sovereignty claims over the South China Sea are difficult to reconcile.*
10. *In what ways has international insecurity in the South China Sea escalated in recent years?*

# Index