TOPIC EYE A-Level Geography

Systems & Landscapes

2020 | 2021 edition

crossAcademe

Systems & Landscapes

2020 | 2021 edition

How to order

Systems & Landscapes 2020/2021 edition is one of four e-magazine titles in our *A-Level Geography Topic Eye* series. Each title comprises 24 pages of topical, thought-provoking articles accompanied by Teacher Notes and PowerPoint-style slides. It is sold in PDF format and only available direct from Cross Academe Limited – see the back cover for details of all four titles.

Each title comes with a site-specific **network licence**, enabling unlimited access for all staff and students. A download link is sent by email to purchasing institutions. Priced individually at £30.00 (+ VAT), all four titles can be purchased for just £90.00 (+ VAT).

For further information or to place an order, visit our website at **www.crossacademe.co.uk** or contact:

Sales Department
Cross Academe Limited
PO Box 105
Rochester
Kent ME2 4BE
t: 01234 56789
f: 01234 565789
e: crossacademe@education.co.uk

ISBN 978-1-911160-35-9

Photographs in this issue have been reproduced by permission of Design Pics Inc/Alamy Stock Photo (front cover), Suzanne Long/Alamy Stock Photo (p. 2), Agatha Kadar/Shutterstock.com (p. 4), Tim Bayliss (p. 7), Paul Abbiss (p. 8), Design Pics Inc/Alamy Stock Photo (p. 10), David Redfern (p. 12), Forest man72/Shutterstock.com (p. 14), guentermanaus/Shutterstock.com (p. 16), Graham Gill (p. 18 and p. 20 top) and Stephen Frink Collection/Alamy Stock Photo (p. 20 bottom).

Design by: Ralph Hall

Published by:
Cross Academe Limited
St John’s House
5 South Parade
Oxford OX2 7JL

Overview

Natural systems, their processes and the landscapes produced by them are integral parts of the A-level specifications. These range from the pre-eminent physical global issue of our time, climate change, to more regional and local processes in coastal, riverine and glacial environments. Within each of these contexts, various feedback mechanisms operate either to exacerbate the processes taking place or to counteract them. A variety of locations can illustrate these mechanisms and their associated landscapes.

Climate change influences all natural systems and landscapes today. Major changes in the ways in which they operate are occurring and adding stress to their mechanisms. *Garrett Nagle* provides an update on the current thinking emanating from the Intergovernmental Panel on Climate Change (IPCC) together with a summary of another somewhat alarming report entitled 'Hothouse Earth'. The latter suggests that we have already entered a critical phase such that a whole series of tipping points could trigger a series of positive feedback mechanisms which could potentially be very damaging to both people and ecosystems.

A systems-based approach (also including feedback mechanisms) to the study of coastal landscapes is essential for A-level study. *Phil Banks* recognises that this is not a straightforward task, since other factors have to be considered for each chosen area of study. Nevertheless, he finds that the wave-cut platform at Flamborough Head (North Yorkshire) illustrates negative feedback within a coastal system, and the barrier beach at Porlock Bay (north Somerset) similarly provides a useful case study of positive feedback. He notes that it is also important to appreciate that further changes, such as those associated with climate change, are likely to interfere with both mechanisms in the future.

David Redfern discovers one of the most spectacular glacial landscapes in the world – Glacier Bay, Alaska. A number of tributary glaciers feed into this tidal bay on the west coast of Alaska, creating stunning scenery. It is unsurprising that large numbers of tourists visit the area, almost exclusively by cruise ship. It is essential that the authorities continue to protect this pristine landscape and the indigenous culture that has developed there, while at the same time allowing significant numbers of people to experience its beauty.

The study of both the water and carbon cycles, and the interconnections between them, is a requirement of all A-level specifications. Perhaps the best context in which to do so is the Amazon rainforest. *Garrett Nagle* examines changes taking place within these natural cycles in this region and also assesses the degree to which a range of human activities are having further consequential impacts. These include agriculture, logging and land clearance by fires, both natural and man-made. He finds that changes within the Amazon are not only creating damaging feedback mechanisms but also impacting on areas well away from it. Furthermore, the Amazon is itself being affected by broader global climatic changes such as the El Niño effect. As a consequence, large areas may be changing into savanna grassland.

Tim Bayliss considers how symbiotic relationships between oceans, climate and biodiversity are changing by focusing on the global importance of coral reefs, their vulnerabilities to climate change and other threats, and the imperative to ensure their protection. With specific reference to the Red Sea, he observes that the scope of local protection initiatives needs to be widened urgently to include more effective local and regional pollution control.

Series contributors
David Redfern (Editor)
Phil Banks
Tim Bayliss
Garrett Nagle
Rebecca Priest

‘Hothouse Earth’ and climate change

At the opening of the Katowice Climate Change Conference in December 2018, David Attenborough declared: ‘We are facing a man-made disaster, our greatest threat in thousands of years. The collapse of our civilisation and the extinction of the natural world is on the horizon.’ *Garrett Nagle* provides an update on current thinking regarding climate change and its management.

In December 2018, at the Katowice Climate Change Conference (COP24), member countries agreed the ‘rulebook’ for implementing the 2015 Paris Agreement and, in particular, how emissions would be measured and the progress in reducing emissions tracked. However, the conference did not tackle the question of how countries would increase their targets to reduce emissions of greenhouse gases. By 2020, countries must show how they have met the targets that they set in 2008. The World Bank also announced that it would increase its funding to tackle global climate change to $200 billion after 2021. However, there was no agreement over the issue of carbon trading. It is hoped that the Santiago Climate Change Conference (COP25) in Chile in 2019 will deal with carbon trading.

Carbon emissions still appear to be rising – largely due to the increased use of coal, oil and natural gas. Atmospheric CO_2 levels reached 405.5 ppm in 2017 compared with pre-industrial levels of 280 ppm. A number of countries at the Katowice Conference failed to support the proposals completely, including the USA, Russia, Australia, Saudi Arabia and Kuwait – all coal, oil and natural gas producers.

Impacts of climate change

The Intergovernmental Panel on Climate Change (IPCC) has warned that even a temperature rise limit of 1.5°C over pre-industrial levels could have catastrophic results for coral reefs, extinction of species and increasing extremes of weather.

There are many potential impacts. Productive agricultural regions are at risk. These provide the world’s food resources and they could suffer from reduced water availability and decreased soil fertility. Coral reefs are a source of food for some 500 million people and account for 10% of marine fisheries. Warming seawater and increased acidification of seawater threaten coral reefs. Tropical rainforests are important for a range of environmental services, but they are under threat from climate change and land use change. Low-lying coastal areas such as deltas are home to millions of people, many of whom live in megacities, and they are at increased risk of coastal flooding, extreme weather events and saline intrusion. In the world’s polar regions, data show that Greenland’s glaciers are melting at an accelerating rate. Between 2002 and 2016 Greenland lost 280 billion tonnes per year, enough to raise global sea levels by 0.75 mm annually. Antarctica is losing 219 billion tonnes annually, which could lead to a rise in sea level of 25 cm by 2070.

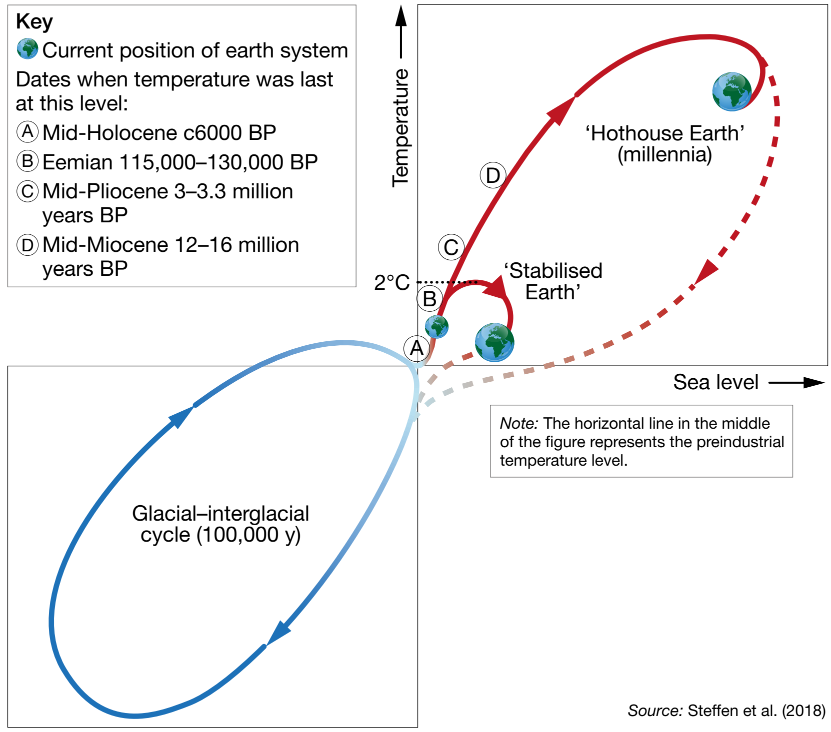
Agriculture is also having a major impact on climate change. The major culprits are meat and dairy producers. They produce just 18% of food calories and 37% of protein but account for over 80% of farmland and 60% of agricultural greenhouse gases. Without meat and dairy production, global farmland could be reduced by over 75%. Freshwater aquaculture is also damaging – fish excreta and uneaten food at the bottom of fish cages lead to anaerobic conditions and produce methane.

'Hothouse Earth'

In a report entitled 'Trajectories of the earth system in the Anthropocene', Steffen et al. (2018) argue that the term 'global heating' should be used instead of global warming. They suggest that the rise in global temperature has moved the earth out of the 'comfort zone' and that it now poses a threat to humanity. Moreover, the UK Met Office announced that the 2018 heatwave was 30 times more likely to be due to anthropogenic (human) causes rather than natural causes. It also announced that the earth is looking at a warming of between 2.5°C and 4.5°C, a situation which could cause the earth to release more carbon rather than to absorb it.

The report states that there is a risk that the earth is entering a new climate phase – called 'Hothouse Earth' – in which the climate will stabilise at a much higher temperature than desired by scientists (Figure 1). It suggests, like the UK Met Office, that temperatures could be as much as 4–5°C higher than pre-industrial levels and warns that sea levels could be some 10–60 m higher than today. This would be much greater than anything over the last 1.2 million years (the Holocene). Such a change may be considered part of the new geological era (the Anthropocene) in which human activities play a major part in physical processes on earth.

The earth's climate may change so much that it will be been taken out of the glacial–interglacial cycles that have characterised the Holocene (Figure 2). In the words of the report, the 'earth system has likely departed from the glacial–interglacial cycle of the late quaternary' and 'it would take in the order of 100,000 years for conditions to return to their pre-pertubation levels'.



Source: Steffen et al. (2018)

Figure 1 *Hothouse Earth – a schematic illustration of possible future pathways of the climate against the background of the typical glacial–interglacial cycles (bottom left)*

Tipping points

The Hothouse Earth report suggests that even an increase of 2°C could trigger a series of positive feedback mechanisms, called tipping points (Figure 3), which throw the earth out of stability. In addition, many of the negative feedback mechanisms that keep the earth stable, such as carbon uptake by terrestrial and marine ecosystems, could weaken.

However, there are uncertainties. For example, increased atmospheric CO_2 has led to increased plant growth and therefore a greater carbon sink. On the other hand, rising temperatures

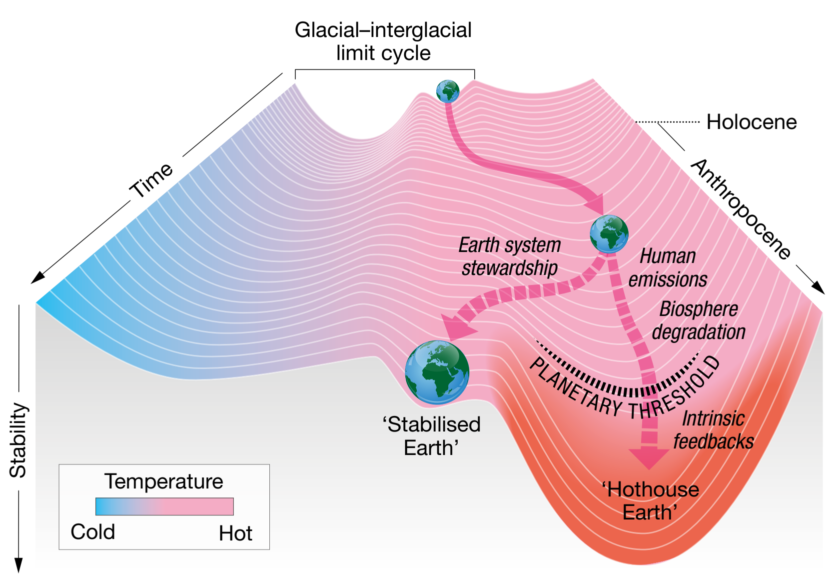
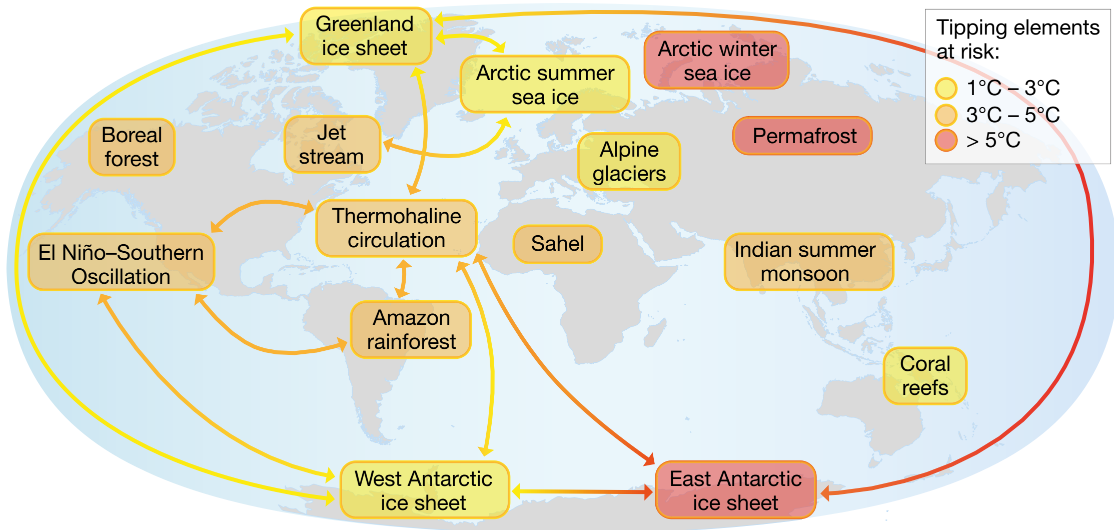


Figure 2 *The earth's climate may be leaving the glacial–interglacial cycles that have characterised the Holocene*

Figure 3 *Tipping points for major world biomes, physical processes and regions*



make leaves hotter, reducing photosynthesis. Furthermore, warming raises soil temperatures, increasing microbial respiration and thereby releasing CO_2 back into the atmosphere.

Scientists are agreed that increased temperatures will result in permafrost melting and the release of some currently frozen carbon. However, they are not agreed on how much carbon and methane will be released – this will depend partly on the size of temperature increase. It is also believed that increasing sea surface temperatures of 1–2°C are likely to lead to increased thermal stratification in the oceans. This will reduce the upwelling of currents and nutrients to the surface, leading to reduced primary productivity and the sinking of organic material (carbon) from the surface to ocean sediments where it may be stored (sequestered).

Can we avoid Hothouse Earth?

In order to avoid Hothouse Earth, there has to be a reduction in greenhouse gas emissions and increased (or new) carbon sinks, whether natural or man-made, such as improved forest, agricultural and soil management, conservation of biodiversity, and carbon capture and storage. In order to achieve a 'stable' climate, there will need to be effective governance at a global level, with much greater emphasis on global planetary concerns regarding trade, economic growth and technological development rather than the nationalistic values and protectionism that have characterised much of the world over the last decade. A different, and somewhat extreme, viewpoint has been expressed by Poore and Nemecek (2018) in an article entitled 'Reducing food's environmental impact through producers and consumers', where they state that the biggest single way to reduce personal environmental impact is to avoid meat and dairy products.

An Arctic landscape in summer, with melted glaciers and a floating iceberg in the Ofjords of East Greenland

Conclusion

The world is entering a new phase in which human activities are having a major impact on many physical processes (such as climate change, acidification of the oceans, air quality and biodiversity decline). Attempts to manage these changes have so far proved difficult. Moreover, the Hothouse Earth report suggests that climate change may well be much more severe than previously indicated and that, if this happens, it could take a hundred thousand years to reverse.

The world is struggling to manage climate change. Although there have been many global conferences, there has still been no definitive action and progress has been limited. Indeed, it has been so limited that we may now be entering a new phase – Hothouse Earth – that causes far more damage than the current target temperature increase of 1.5°C. TE

REVIEW

Key points

- The world is facing a man-made disaster – climate change – and we are struggling to manage it.
- Atmospheric carbon emissions have reached over 405 ppm.
- Despite the many negative impacts of climate change, nations and individuals continue to use fossil fuels on a massive scale.
- The IPCC has warned that even if the global temperature rise is kept to 1.5°C, there could be an increase in extremes of weather, extinction of species and a decline in coral reefs.
- A Hothouse Earth report suggests global warming in the region of 2.5–4.5°C.
- An increase of just 2°C could trigger a series of possible feedback mechanisms that throw the earth out of stability.
- In order to avoid Hothouse Earth, political action is needed on a global scale, alongside individual lifestyle choices, such as eating less meat.

Pause for thought

Concern about climate change has increased in recent decades, but very little action has been taken. Although some agreement was reached at the Katowice Climate Change Conference, the focus was on how emissions would be measured and tracked rather than on how they could be reduced. There are many countries worldwide that are still developing their coal, oil and natural gas resources with little regard for their impact on the environment and/or future generations, and there are still many individuals who are doing little to reduce their environmental footprint. Such inactivity is likely to have an impact in the future.

Context

As global climate change continues, we may be entering a new era. We may be approaching a tipping point from which it could take hundreds of thousands of years to return. The consequences for the earth's climate, biodiversity and the human race in Hothouse Earth look bleak. Climate change needs to be tackled not only at a global political level (such as at UN conferences) but also at an individual level (e.g. reducing personal consumption of meat).

RESPONSE

Assimilation

1. Outline how agriculture damages the world's atmosphere.
2. According to the Hothouse Earth report, by how much will the earth's climate heat up?
3. On what timescale do glacials and interglacials occur?
4. Explain the term 'tipping point'.
5. Give an example of a tipping point.
6. At what temperature increase will (a) the Amazon rainforest and (b) the Greenland ice sheet reach a tipping point?
7. Outline possible ways to avoid Hothouse Earth.

Evaluation

1. Outline the main impacts of global climate change.

   ANSWER PLAN

   Global climate change has many impacts:

   - Global temperatures are rising, especially in high latitude regions such as the Arctic.
   - Agricultural patterns may change and that will impact food supplies – more people could experience hunger as a result of lower agricultural yields but greater demands for food.
   - Many ecosystems are at risk, especially high altitude and high latitude ones that have fewer options for their spread – some keystone species, such as polar bears, are particularly at risk.
   - Rising sea levels threaten many coastal regions.
   - Increasing storm intensity also threatens many coastal areas.
   - Disease patterns are likely to change, with malaria becoming more widespread as temperatures rise.
   - Acidification of the oceans threatens coral reefs and shell-building organisms.

2. Suggest reasons why it is difficult to manage global climate change.
3. Explain the Hothouse Earth concept.
4. Explain how feedback mechanisms operate in Hothouse Earth.
5. Suggest why Hothouse Earth may lead to different impacts compared to the current level of global climate change.
6. Examine the ways in which Hothouse Earth may be avoided.

Extension

1. For details about Hothouse Earth, visit: **www.pnas.org/cgi/doi/10.1073/pnas.1810141115**
2. Find out how individuals can have an impact on reducing climate change: **http://science.sciencemag.org/content/360/6392/987.full?ijkey=ffyeW1F0oSl6k&keytype=ref&siteid=sci**
3. Investigate the Katowice Climate Change Conference (COP24): **https://cop24.gov.pl/**

Feedback mechanisms in coastal landscapes

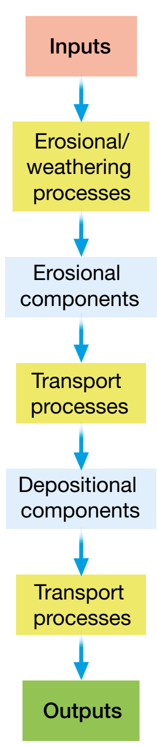
All A-level specifications require students to study landforms through a systems-based approach. *Phil Banks* examines the structure of geomorphological systems with particular reference to coastal landscape development.

Since the earth is highly complex, geographers have attempted to simplify aspects of it so that relationships between components can be better understood. These simplifications are called models. One type of model that is widely used, particularly in physical geography, is the **system**.

A system is an assemblage of interrelated parts that work together by way of some driving process. It is a series of **stores** or **components** that have **flows** or **connections** between them. Relationships between various parts of a system determine how any particular process is carried out. Most systems share common characteristics:

- they are generalisations of reality, removing incidental detail that obscures fundamental relationships;
- they function by having **inputs** and **outputs** of material (energy and/or matter) that is processed within the components, causing it to change in some way;
- they involve the **flow** of material between components.

Figure 1 *The coastal open system for a stretch of coastline*



System feedback

Some coastal landscapes can be seen to be open systems (Figure 1) that are in a state of dynamic equilibrium. Energy and matter can enter and leave the system.

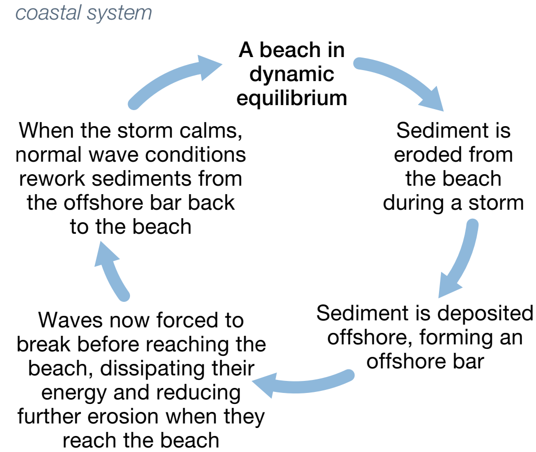
When inputs and outputs within a coastal system are the same, then a state of **dynamic equilibrium** exists. An example of this would be when the rate of sediment being added to a beach is the same as the amount leaving the beach, resulting in the beach remaining the same size. If any inputs, processes or outputs change either because of environmental or human factors, then the system becomes unbalanced and will change to restore equilibrium. When an initial change within a system brings about further change in the same direction, this is known as **positive feedback**. When a system returns to equilibrium following a change in the system, this is known as negative feedback. It is **negative feedback** that allows systems to adjust to short-term changes, e.g. storms can move huge quantities of beach material in a short time. After reverting back to normal conditions, sediment is slowly shifted so that equilibrium is restored and the beach looks much the same as before the storm (Figure 2).

Case study of negative feedback: Flamborough Head

Flamborough Head is a headland composed of 30–50 m high near-vertical chalk cliffs on the coast of the East Riding of Yorkshire. It is made predominantly of chalk, which at Flamborough is relatively hard in comparison to the clay cliffs of Holderness to the south. The cliffs are eroding at a slow rate (0–0.4 m per year). At the foot there is a rocky wave-cut platform cut into the chalk that in places extends for up to 1 km offshore. This shore platform results from the following process:

- Erosion is concentrated at the base of the headland, where wave processes undercut the cliff to create a wave-cut notch.

Figure 2 *An example of negative feedback in a coastal system*



Flamborough Head with its wave-cut platform partially exposed by low tide

- Eventually the notch is so deeply incised that the weight of the overlying rock causes the cliff to collapse.
- As the cliff collapses, it retreats landwards. The layer of flat rock that is left behind is called a **wave-cut platform**. The platform typically has a slope of less than 4° and is often only fully exposed at low tide.

The wave-cut platform has a significant impact on the ability of waves to erode the base of a cliff. It varies considerably in relief both out towards the sea and along the platform. The roughness of the platform plays a part in reducing the energy available for marine erosion of the foot of the cliff and the removal of eroded material from its base. This is because as the platform grows, the waves have further to travel in very shallow water and much of their energy is dissipated by friction. Waves tend to break earlier, before they can erode the base of the cliff. The negative feedback is illustrated in Figure 3.

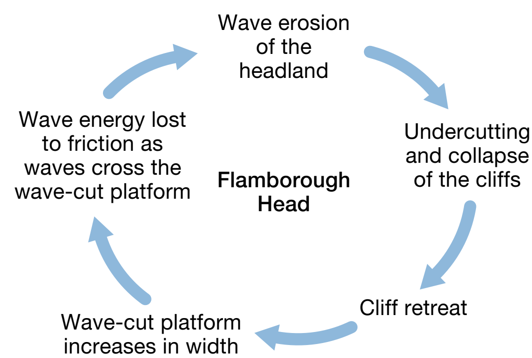
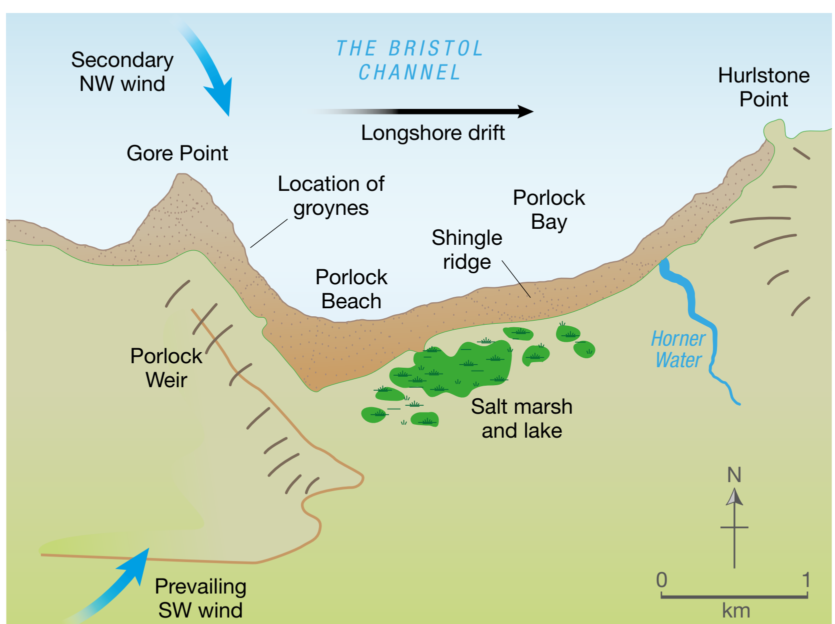


Figure 3 *A system diagram showing negative feedback at Flamborough Head*

Case study of positive feedback: Porlock Bay barrier beach

The 5 km long barrier ridge at Porlock Bay, North Somerset (Figure 4) is the longest continuous shingle and pebble barrier system on the western coast of Britain. Landward of the ridge, a marsh, Porlock Marsh, extends almost 1 km inland. The cliffs to the west of Porlock were covered by **head deposits**, sediments formed under periglacial conditions generally composed of a clay matrix with a wide range of sizes of angular rock fragments. As sea levels rose following the melting of ice sheets at the end of the last major glacial about 11,500 BP, these head deposits were eroded from the cliffs and transported eastward by **longshore drift**. Fine clays were moved past Porlock Bay, but the rock fragments were

Figure 4 *Porlock Bay and beach*



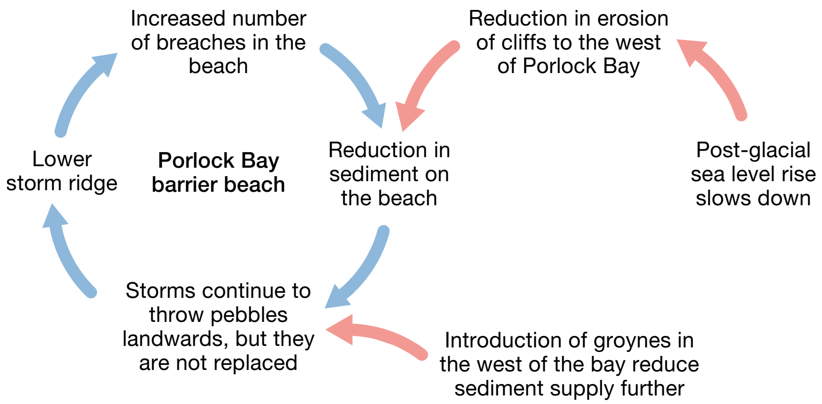


Figure 5 *A system diagram showing positive feedback along the coastline of Porlock Bay*

deposited as a spit. This gradually extended out across Porlock Bay to become a barrier beach with an enclosed freshwater marsh and meadows behind, fed by a number of streams and small rivers. A storm beach composed of coarse shingle and pebbles (5–20 cm diameter) developed as Atlantic storms hit the bay and hurled the pebbles above the reach of all but the highest waves.

As the rate of sea level rise decreased in the last 2000 years, erosion of the head deposits and so supply of new beach material virtually ceased. In addition, the construction of groynes at Gore Point and sea walls at the back of the beach to protect the main road in the early nineteenth century has interrupted and reduced the sediment supply entering the system from the west. At the same time, a lot of beach material is being lost as a result of:

- the steady movement of beach material east by longshore drift and its consequent accumulation at the Hurlstone Point end of the barrier;
- highly destructive storm waves and overtopping events (where sediment is carried over the ridge by storm washover).

View looking westwards along Porlock Beach and shingle ridge towards Porlock Weir and Gore Point

The reduction in volume of the ridge has resulted in increased instability (Figure 5). Prior to 1996, the response to this thinning and stretching of the beach was to use beach regrading and replenishment techniques to move shingle from areas where there was still some accumulation to somewhere that was losing material. This had the effect of thinning the ridge along much of the beach.

In 1996, a deep depression and south westerly gale caused storm surge levels that were superimposed on the high tide to exceed the height of the barrier. Massive overwashing of salt water demolished the barrier crest and moved gravel into the area behind the barrier. Seawater flooded the marsh area. As the tide fell, the water rushing back out to sea opened a breach in the ridge that was so large that it was considered to be impossible for it to repair naturally. In fact, it widened considerably. Since the 1996 breach, the coast has been managed by coastal adaptation where it has been allowed to develop naturally. The former freshwater marsh is now a saltmarsh.

Conclusion

In practice, the application of a systems approach to coastal landscapes has not been very successfully utilised. This is mainly due to the complexity of the coastal system. This complexity increases with the scale.

Negative feedback should always be just a self-contained loop (as shown in Figure 2), but Flamborough Head is complicated by other factors such as wave and wind direction, wave refraction, rock structure and changing sea levels. It is acceptable to take these factors out of consideration because one of the purposes of geographical modelling is to simplify the examination of geographical phenomena. For Porlock Bay and its positive feedback, extensions that exacerbate the initial change are acceptable. This means that management, for example, can be taken into consideration.

Both places are simply the end result of a very long process of coastal landscape formation that originated as sea levels rose following the end of the last ice advance. Future changes to the inputs of the systems, such as sea level rise, are going to throw the systems out of balance with massive consequences for coastal managers. TE

REVIEW

Key points

- A system is a type of *model* used by geographers to help us understand how aspects of the human and physical landscape interact with one another.
- If an output of a physical process goes back into the process that caused it, this is called *feedback*.
- Positive feedback acts as a destabilising factor because it brings on further change.
- Negative feedback tends to dampen any further change and so it is a stabilising factor.
- The creation of wave-cut platforms at the base of cliffs acts as a negative feedback because the wider the wave-cut platform the slower the cliff retreats.
- The breach in Porlock shingle ridge has acted as positive feedback because there is insufficient sediment supply to overcome the gap. The scouring effect of outgoing tidal water from the new saltmarsh behind the barrier beach not only maintains the breach but also makes it wider.
- A new management scheme of coastal adaptation to the change was the first of its type in the UK.

Pause for thought

- Coasts are a dynamic environment with conditions changing all the time. It is too simplistic to isolate just one of these changes and then attempt to explain its impact.
- Those responsible for coastal protection and management must not only take past processes into account when forming a shoreline management plan but also predict future changes to the system as a result of changes to climate and human demands on that coastline.

Context

- Both Flamborough Head and Porlock Beach present challenges to coastal managers, particularly in the context of rising sea levels and more extreme weather events.
- An increase in sea level will mean that the dampening effect of the present wave-cut platform will decrease.
- More violent storms and rising sea levels will overwhelm Porlock Beach, making the land sheltering behind it vulnerable to attack.

RESPONSE

Assimilation

1. Define the term ‘system’ in the context of physical geography.
2. Explain why some coastlines could be described as ‘open systems’.
3. Explain the distinction between positive and negative feedback in the context of geographical systems.
4. Describe the landforms that can be found at Flamborough Head.
5. What is the role of the wave-cut platform in reducing the rate of cliff retreat at Flamborough Head?
6. How did rising sea level contribute to the formation of Porlock Beach?
7. What do you understand by the term ‘coastal adaptation' in the context of coastal management?

Evaluation

1. With the use of examples, assess the extent to which feedback plays a role in the development of coastal landforms.

   ANSWER PLAN

   A well-structured response should include the following:

   - A brief definition of feedback and an introduction to the examples that are going to be used. Include at least one example of positive feedback and one of negative feedback.
   - Describe the processes taking place in your chosen examples and show how the coastline has been formed.
   - For each example, show how feedback has either accelerated the landscape development to a point where it begins to break down *or* acted as a dampening force to maintain equilibrium.
   - Include a summary statement where you make a comparative assessment based on what you have already written.

2. Explain why the breach in Porlock Beach meant that the management of the beach had to be changed from one of replenishment to one of coastal adaptation.
3. Outline the differences between hard and soft engineering with respect to managing coastal landscapes. With the use of examples, assess their effectiveness.
4. With the use of examples, assess the impact that climate change may have on the ways that coastlines are managed in different parts of the world.
5. ‘In the long run, natural processes of coastal formation are much too powerful for any hard engineering management to prevent.’ To what extent do you agree with the above statement? Use examples to support your argument.

Extension

1. Visit the Exmoor National Park document that gives a detailed account of the formation and ongoing problems with Porlock Beach: **www.exmoor-nationalpark.gov.uk/learning/coastal-management-in-porlock-bay**

Glacier Bay, Alaska

A remote glacial landscape wilderness

David Redfern discovers one of the most spectacular glacial landscapes in the world. A number of tributary glaciers feed into a tidal bay on the west coast of Alaska, creating stunning scenery. It is unsurprising that large numbers of tourists visit the area, mostly by cruise ship.

Figure 1 *Location of Glacier Bay*

The Glacier Bay National Park and Preserve is part of a larger 25 million acre World Heritage Site that straddles the USA–Canada border in the northwest of North America. The site is one of the largest protected areas in the world and has been designated as such by UNESCO. It comprises 3.3 million acres of mountains, glaciers and forests (Figure 1).

Glacial history

As in Europe, North America has been subject to a series of glacial advances and retreats, known as the Ice Ages. The furthest extent was as far south as the upper Mid West (present-day Montana and the Dakotas) in the USA over the last 10,000–20,000 years. The glaciers found in Glacier Bay are, however, the product of a slight cooling in the planet's atmosphere in the seventeenth and eighteenth centuries, peaking in 1750 – a period known as the 'Little Ice Age'. Glaciers advanced from the northwest (along the course of what is now followed by the Grand Pacific Glacier), from the west off the Brady Icefield and from the east (along the course of the present-day Carroll Glacier) down into a broad valley. They eroded the present-day bay, which later filled with seawater.

In 1795, one of the earliest explorers in the area, Captain George Vancouver, mapped the bay, showing that it stretched 5 miles inland. In 1879, the conservationist John Muir explored the area by canoe and wrote that the glacial ice had retreated by another 40 miles. Today, cruise ships sail 65 miles up the bay to reveal the spectacular scenery to tourists. Many of the glaciers in the bay are currently retreating, such as the Rendu Glacier; some are advancing, such as the Johns Hopkins Glacier; and some, such as the Margerie Glacier, are currently stable, neither growing nor receding (Figure 2).

The glaciers

About a dozen tidewater glaciers can be found in the bay. They are largely located at the heads of the smaller inlets within the larger bay, flowing from the mountain and ice fields that surround it. They calve small and large icebergs into the water, creating a sea surface that is littered with floating ice blocks in the freezing cold water. Some of the glaciers fit the usual description of glaciers – moving tongues of crevassed white ice with very pronounced snouts. These include the Margerie Glacier and Lamplugh Glacier. Others, such as the Grand Pacific Glacier, are covered with huge deposits of sediment and moraine so that their coloration makes it difficult to see they are made of ice.

Margerie Glacier is perhaps the most stunning of the glaciers in the bay. It is 34 km long, beginning on the slopes of Mount Root. It flows southeast and then north-northeast to its terminus in Tarr Inlet. It is a highly active glacier with calving taking place frequently at the water's edge. The snout's current stationary state means that ablation at the snout is being balanced by accumulation at its source. Its maximum width is 1.5 km and its height at the terminus is 110 m, 30 m of which is underwater.

As the glaciers shed into the water, they also deposit sediments from within their mass at the tidewater face of each glacier. This has created a protective shallow shoal in front of the glacier snout but under the water line (Figure 3). This shoal is crucial for maintaining the snout of the glacier or, at least, reducing its retreat. In some parts where the shoal has been removed by submarine currents, the underside of the glacier can be subject to attack from seawater and retreat can be more rapid.

Vegetation succession

While the more remote areas of the bay consist largely of bare rock, other than those covered by snow and ice, forests now cloak the more southern shores. The area is of great interest to scientists to examine how vegetation species colonise bare rock surfaces after relatively recent exposure. The area provides an example of a pure natural succession from bare rock through to pioneer species, mosses and lichens, to the climatic climax plant community of coniferous woodland. This succession is called a lithosere.

Near the mouth of the bay, spruce and hemlock forests dominate the landscape. These lands began emerging from the ice around 300 years ago and have had the most time to recover from the effects of the glaciers. Moving north up the bay, the landscape is more recently revealed from the ice. The more mature spruce and hemlock forests give way to fast-growing deciduous forests of cottonwood and alder, which in turn give way

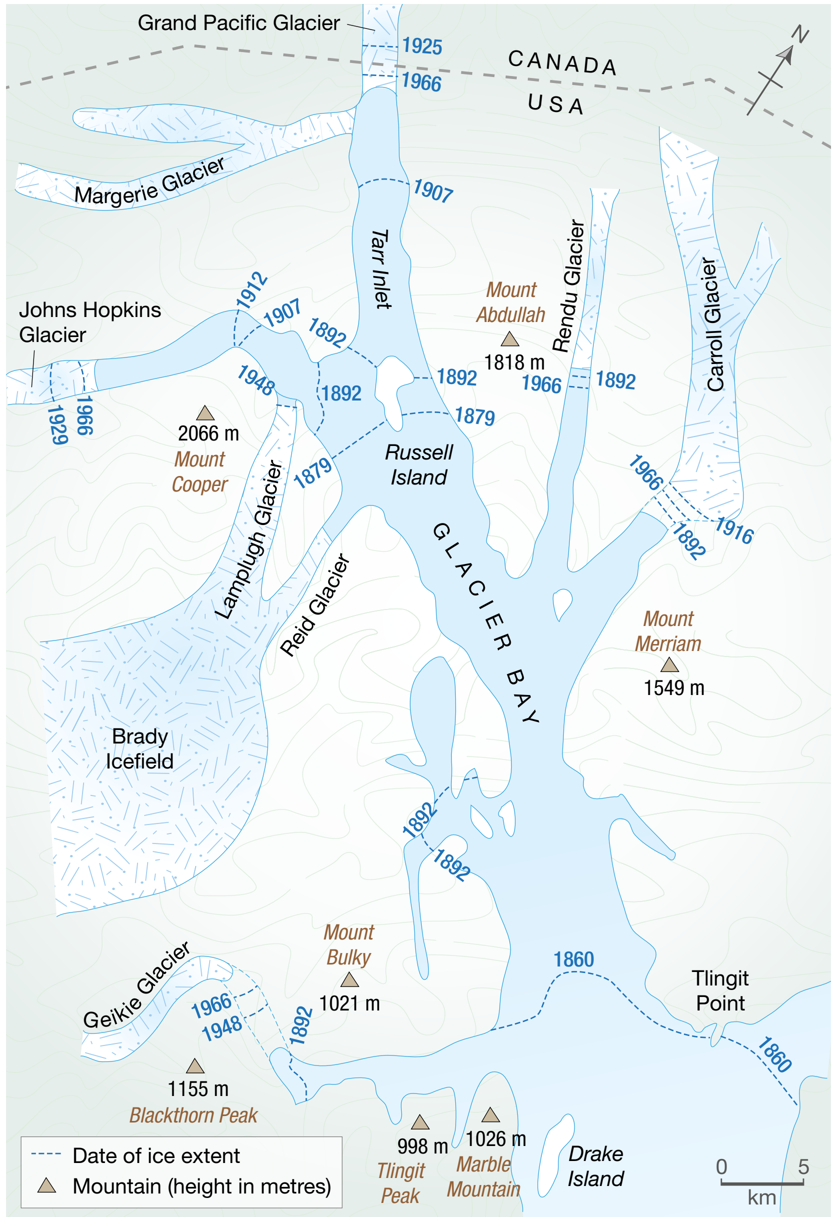


Figure 2 *Main features of Glacier Bay*

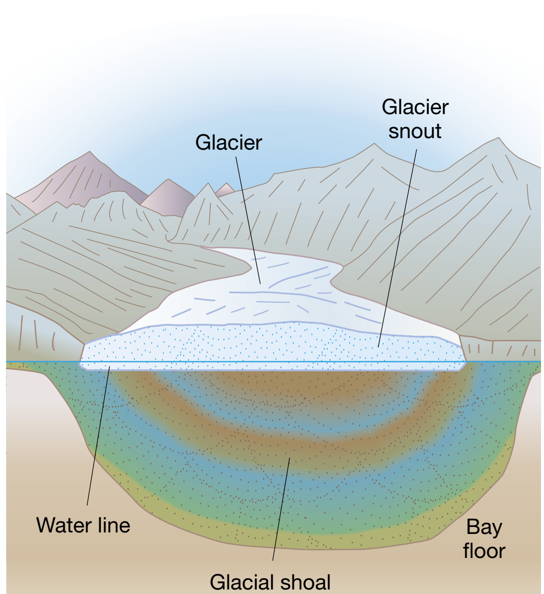
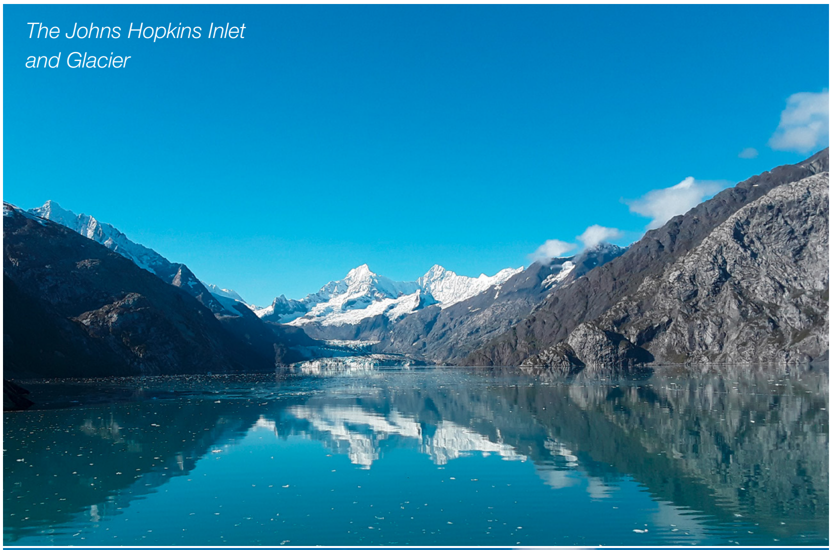


Figure 3 *A glacier shoal*


The Johns Hopkins Inlet and Glacier


Margerie Glacier's snout

to shrub lands and then tundra, until near the glaciers there is nothing growing at all.

First Nations people

In the late 1600s, the area had been colonised by Tlingit people, before they had to move out due to the ice advancing. These are the indigenous people of the Pacific Northwest coast of North America. There are signs of their occupation in the southern part of the bay, near present-day Bartlett Cove, in the form of totem poles and distinctive wooden houses. This settlement would have served as a summer fish camp, before movement south in the winter. Salmon are still very common in the area, giving rise to large populations of sea otter and sea lions.

Today, the Tlingit ancestors claim Glacier Bay to be their spiritual homeland. They have a distinctive culture in that they have a matrilineal kinship system – children are born into the mother's clan or tribe, and property and hereditary roles pass down the mother's line. This is unlike most other cultures in the world.

Tourism in the bay

Access to the bay is by boat or plane only. One road exists in the extreme south of the bay, where a short 15 km stretch connects the Glacier Bay Lodge Visitor Centre in Bartlett Cove to the small Gustavus Airport. Vessel permits are needed to access the area, and they are only issued to cruise ships between 1 June and mid-September. Some areas are closed periodically because of bears (brown/grizzly and black), nesting birds and humpback whales.

The great majority of tourism in the bay is undertaken by cruise ship. On any one day, three or four ships can visit, each under strict time constraints. Depending on the sequence for your particular ship, it is possible to view a ship a couple of miles ahead of you in one direction, and then turn 180° to see another ship two miles or so behind you. They are not allowed to dock anywhere in the bay.

The length of stay is typically 9–10 hours, including an hour-long stop, lingering off the edge of a tidewater glacier, such as the Margerie Glacier in Tarr Inlet. Ice blocks frequently fall (calve) from the glacier snout. The thundering crack of ice breaking off is the first thing you hear, followed a few seconds later by the sight of a block, or blocks, of ice falling into the water, with a subsequent huge splash. Ice flows are all around; occasionally the heads of sea otter and seal can be seen amongst them.

Temperatures in the summer average 13°C, though they can be much colder. Even on the cruise ships, people must guard against hyperthermia and wear appropriate clothing while on open deck. Rain is common, as on average this part of Alaska only receives about 4 days of sun per month at this time. Park Rangers are sent to each ship to give descriptive commentary over the ship's tannoy system – while informative, this contrasts greatly with the eerie silence all around.

Conclusion

Glacier Bay provides a stunningly beautiful context within which to see some of nature's processes taking place in a cold environment. It is hoped that the authorities continue to protect the pristine landscape while at the same time allowing significant numbers of people to experience this remote wilderness. TE

REVIEW

Key points

- Glacier Bay National Park, Alaska, is one of the largest World Heritage Sites and is a spectacular example of a glaciated landscape.
- The landscape owes its origin to the period of ice advance during the seventeenth and eighteenth centuries – a time known as the 'Little Ice Age'.
- A number of tidewater glaciers can be found within the bay, several of which are in retreat.
- The bay also provides visible evidence of natural plant succession – a lithosere.
- A distinctive human culture has evolved in the area, evidence of which still remains.
- Due to all these features, tourism is of major importance and presents challenges to national park managers.

Pause for thought

- Most exemplar glaciated landscapes in textbooks are based on ice advances and retreats that took place in the geological era of the Quaternary – up to 2.5 million years ago. How useful is it to have an example of a glaciated region which is much more recent in origin and where glacial processes are still very active?
- To what extent does the area's relative youth enable study of the interplay of the physical environment with vegetation and early human activity?
- The area has breathtaking scenery that many people want to see and experience. In what ways do tourism and its management present specific and significant issues here?
- What impact will climate change have on the area and on access to it?

Context

The study of a glaciated landscape beyond the UK is a requirement of the revised A-level specifications. Glacier Bay, Alaska, provides an interesting example. There are two distinctive aspects that make the region worthy of study: first, the glacial processes that have created the landscape are relatively recent geologically, and are ongoing; secondly, the area provides an interesting context for the study of human interaction with such an environment.

RESPONSE

Assimilation

1 Using Figure 1, describe the location of Glacier Bay, Alaska.

2 Describe the changes in the length of the glaciers in the bay between 1795 and the present day.

3 Why are the waters of Glacier Bay 'littered with floating ice blocks'?

4 Explain how a glacial shoal develops and why it is important in maintaining the integrity of a tidewater glacier snout.

5 Outline the features that make the culture of the Tlingit people different.

6 Describe how tourism by boat is carefully managed in the bay.

Evaluation

1 For a glaciated landscape you have studied in the UK, to what extent is it dominated by erosional, depositional or fluvioglacial processes?

ANSWER PLAN

- Describe the geographical setting of the area, with names and descriptions of key landforms.
- Outline the processes by which the key landforms were formed.
- Ensure that you make links between the different processes and the landscape.
- Identify anomalies in the landscape where the links are either not clear or go against the usual relationships.
- Provide an overall summative statement of the extent of domination by one (or otherwise) of the glacial processes.

2 Draw a labelled sketch of the landscape shown in the photograph of the Johns Hopkins Inlet and Glacier to illustrate the main landforms.

3 Using Figure 2, analyse the changes in the positions of glacial snouts in the bay.

4 Compare a lithosere that takes place in Glacier Bay with one in the UK.

5 With reference to *one* example of a glacial landscape you have studied, evaluate the *impact* of human activity and management on the landscape.

Extension

1 A video of the landscape around Glacier Bay, including the spectacle and excitement of calving tidewater glaciers, can be found at: **www.nps.gov/media/video/view.htm?id=C75D1EEC-1DD8-B71C-07CC4CB0F951412F**

2 A view of how tourism in Glacier Bay has changed over 100 years can be found at: **www.nps.gov/media/video/view.htm?id=C67E76D6-1DD8-B71C-0729E208D3D284C4**

3 An account of how glaciers in the neighbouring Canadian Yukon territory are shrinking due to climate change can be read at: **https://amp.theguardian.com/world/2018/oct/30/canada-glaciers-yukon-shrinking**

Amazonian carbon and water cycles

The carbon and water cycles are integral parts of the world's ecosystems. *Garrett Nagle* looks at the interconnections between the two cycles in the Amazon rainforest – perhaps the most important ecosystem on the planet. Changes resulting from a variety of human activities are increasing pressures on both natural cycles.

The Amazonian biosphere contains 90–140 × 10^9 tonnes of carbon, equivalent to approximately 90–140 years' worth of current global anthropogenic carbon emissions. Amazonia plays a vital role in the global water cycle too. Approximately 8 × 10^{12} tonnes of water evaporates from Amazon forests each year. The rest of the rainfall entering the Amazon basin flows into the Atlantic Ocean, accounting for around 15–20% of the worldwide continental freshwater runoff to the oceans.

Carbon storage uncertainties in Amazonia

Amazonia is an incredibly important carbon store, accounting for one quarter of the carbon dioxide absorbed by the land globally each year. In theory, as anthropogenic carbon dioxide emissions increase, forests will absorb and store more carbon, provided they have enough water and nutrients to grow. However, some academics believe that the Amazon has already passed a threshold in terms of how much surplus carbon it can store. The combination of relatively constant productivity and increasing tree mortality means that carbon storage in the Amazon has declined by around 30% since the 1990s.

Forest dieback is a condition where a large number of trees are killed due to environmental conditions such as drought, high temperatures, pollution (e.g. acidification) or diseases. One explanation is that the faster trees grow (in response to a greater abundance of carbon dioxide), the sooner they reach maturity and the sooner they age. As taller trees are more vulnerable to high winds and drought, faster growth – on account of enhanced greenhouse gas emissions and greater atmospheric carbon storage – may place trees at increased risk from weather extremes.

During droughts in Amazonia during 2005 and 2010, there were increased peaks of mortality, albeit short term. Nevertheless, some researchers believe that drought may be a possible underlying reason for declining carbon storage. In one study, researchers found that above-ground biomass declined by as much as 25% during droughts. Total wood production decreased by around 12% and the leaf area index also declined.

This latter effect reduces the ability of trees to photosynthesise.

Local system changes in Amazonia driven by human activity

(a) Agriculture and land use conversion

There are mounting human pressures to convert parts of the Amazon rainforest to arable and pastoral farmland, resulting in further reductions in terrestrial carbon storage and water cycle interception storage. Several such pressures exist:

- Since the eradication of foot-and-mouth disease in large areas of southern and eastern Amazonia, the region's cattle and pig industries have been expanded.
- The increasing international demand for agro-industrial commodities has coincided with a scarcity of appropriate land in the USA, Western Europe and China.
- The rising price of oil has stimulated the expansion of the biofuels industry (Figure 1) – the Brazilian sugar cane industry is one of the world's most efficient and inexpensive forms of ethanol, and palm oil is one of the most efficient sources of biodiesel.

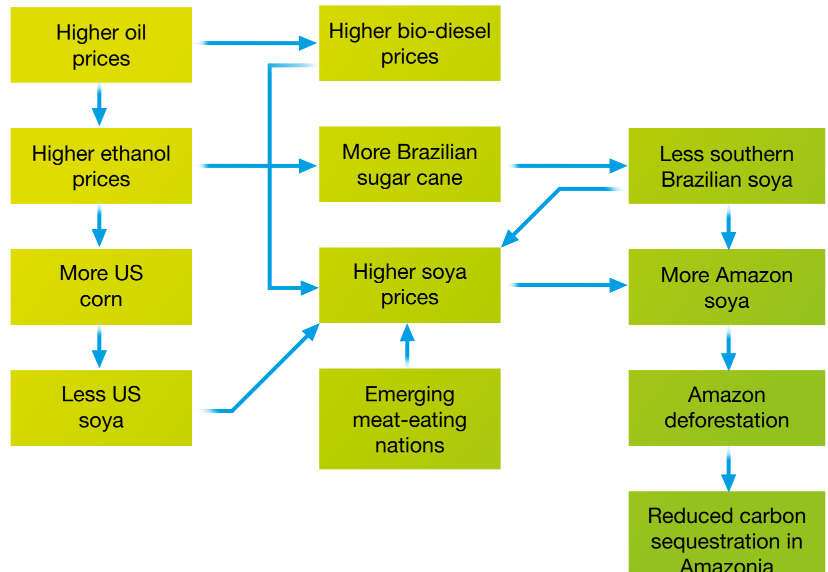
(b) Damage caused by fire, fragmentation and logging

Parts of Amazonia experience a dry season (defined as any month with less than 100 mm of rain), which generally lasts from July to September. In fact, nearly half of the forests of the Amazon maintain full leaf canopies during dry seasons that range from three to five months, indicating a high tolerance of drought. These forests have many trees with deep roots and are able to avoid severe drought stress by absorbing moisture stored deep in the soil. However, such tolerance has its limits.

Land use activities increase forest susceptibility to fire during periods of drought by providing ignition sources, by fragmenting the forest and by thinning the forest through logging (Figure 2). Although ignition from lightning is rare, man-made sources of ignition are increasingly abundant. Forests are burned in preparation for crops or pasture and to improve pasture forage. However, these fires frequently burn beyond their intended boundaries into neighbouring forests. During the severe drought of 2005, at least 3000 km^2 of standing forest burned in the southwest Amazon. These low, slow-moving fires can kill up to 50% of trees (above 10 cm in diameter). Forest fire can increase susceptibility to further burning in a positive feedback by killing trees, opening the canopy and enabling increased solar radiation to reach the forest floor.

Forest degradation is also fostered by fragmentation and further effects associated with forest clearcutting for pasture formation. This is because tree mortality and forest flammability are higher along forest edges.

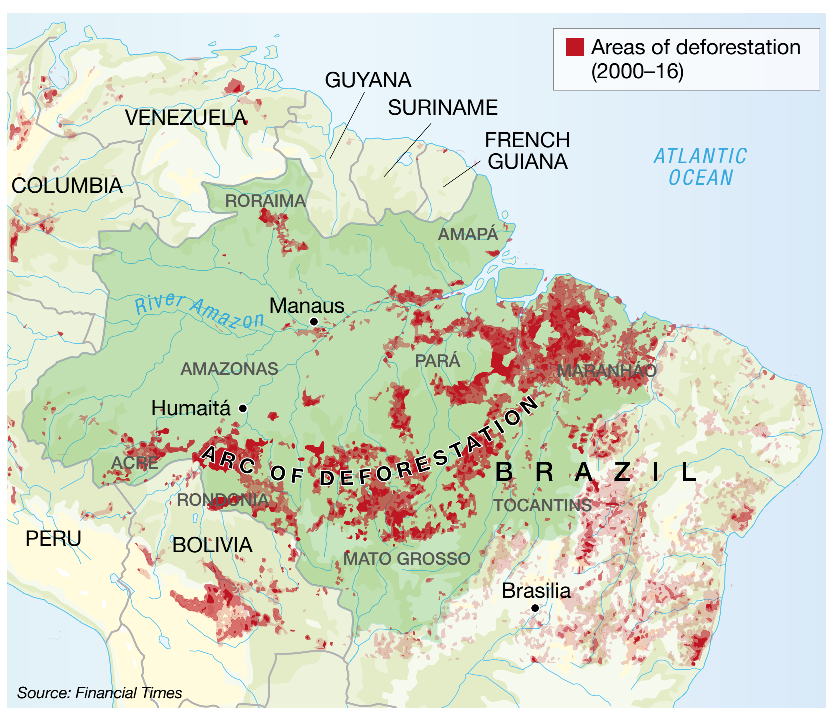
One projection for 2030 suggests that 31% of the Amazon's closed canopy forest formation will be deforested and 24% will be damaged by drought or logging. If 'business as usual' continues, logging will further reduce the



Source: Nepstad, D. C. et al. 2008

Figure 1 *Interactions between changing global economic systems (commodity prices) and carbon and water cycle changes (Amazon deforestation)*

Figure 2 *Deforestation in the Amazon, 2000–16*



Deforestation reduces the stores of both carbon and water

Amazonian forest carbon store size by 15%; drought damage will cause another 10% reduction in forest biomass. The effects of more frequent fires could be to release an additional 20% of forest carbon into the atmosphere.

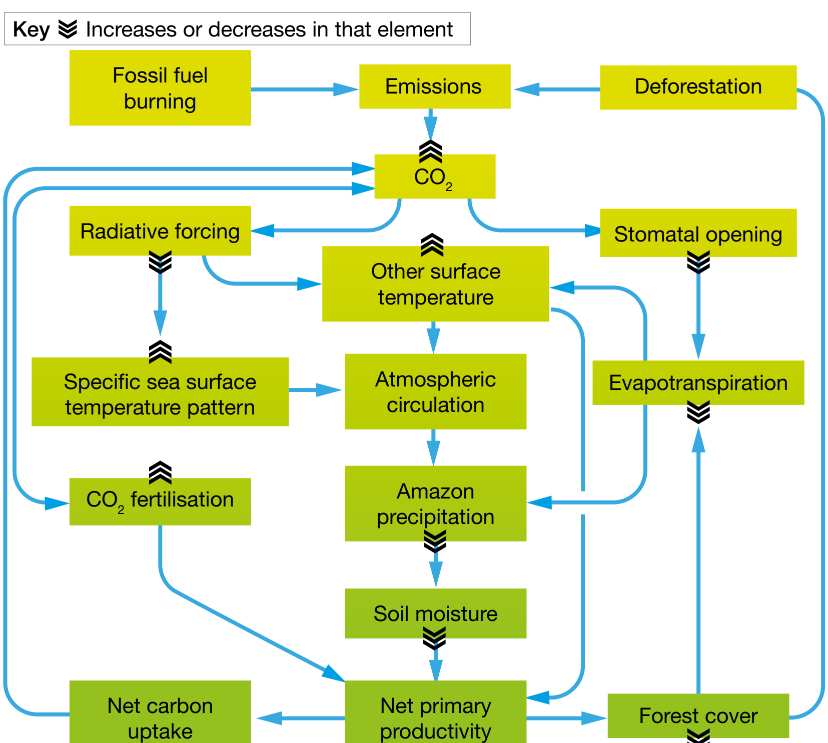
Water cycle feedback and its implications for carbon cycling

Evidence suggests that the eastern Amazon may be drier in future as a result of system feedback. It now appears that any clearing beyond approximately 30% of the forests of the region may trigger a decline in rainfall. Rainfall in the region may decline by as much as 20% by 2100. Water cycle deficits may become more common in places where there are fewer trees because of reduced evapotranspiration rates. This would most likely represent a long-term and permanent decline in water availability.

There are also other reasons for water budget deficits on varying timescales:

- The cyclical occurrence of drought in parts of Amazonia is linked with changes in sea surface temperatures (SSTs) along the Pacific coast of South America. If SSTs increase, rainfall decreases in the Amazon. This typically happens during El Niño events. Studies show tree mortality in central Amazonia increasing from around 1–2% in El Niño years.
- Changing water availability can also occur over a shorter timescale due to the outbreak of fire. This can lead to reduced rainfall. Anecdotal evidence from Mato Grosso suggests that the rainy season begins later in the year by several weeks when the density of smoke is high.

Figure 3 *Potential feedback mechanisms involved in Amazonian climate change and forest degradation*



Source: Betts, R. et al. 2008

Climate change and forest change interactions

The climate and air quality in Amazonia depend strongly on the character of the vegetation cover, and any large-scale changes in vegetation cover would therefore be expected to modify the local climate and contribute to global climate change through the release of stored carbon. Global climate change may lead to reductions in precipitation in Amazonia, which would in turn trigger a cascade of biosphere changes including effects on flora, fauna and soils.

Forest loss leads to less availability of water locally (less interception and more overland runoff reduce evaporation). Although there is more heating, there is less convectional rainfall, as some of the water has flowed out of the area. Forest loss also increases surface albedo, which reduces convection, causing a further positive feedback on rainfall reduction (Figure 3).

Conclusion: towards a tipping point

Economic, ecological and climatic systems in Amazonia may now be interacting in ways which will move the forest beyond a threshold, or tipping point, and change it to savanna grassland. Multiple human and physical processes are involved including forest clearance and thinning, fragmentation, fires and period droughts linked with El Niño events. Climate change further reinforces many of these processes by increasing air temperatures, dry season severity and the frequency of extreme weather events. TE

REVIEW

Key points

- The operations of the water cycle and the carbon cycle are closely interrelated, both at local scales and continental scales.
- Deforestation radically alters carbon and water storage and flow patterns; appropriate forest management practices can help limit changes in both systems.
- Amazonia is a globally important carbon and water store that is under great pressure due to drought.
- There is uncertainty surrounding interactions between climate change and forest change in Amazonia, particularly in relation to the rainforest's capacity to serve as a 'sink' for anthropogenic carbon emissions.
- There is evidence of forest dieback in the Amazon – this may be due to faster growth, earlier maturity and accelerated death.
- There is a clear link between the decline in biomass and the decline in water availability in the Amazon.
- Many scientists believe that the Amazon is reaching a tipping point and could develop into a savanna grassland.

Pause for thought

Increasingly frequent drought is correlated with increased biomass mortality, which releases carbon into the atmosphere and contributes to global climate change. Land use changes and, in particular, the conversion of forest to agricultural land use have added to forest decline and increased the release of carbon into the atmosphere. Forest fires, mainly started by human activities, often burn beyond their intended area and are responsible for the release of stored carbon into the atmosphere. Water cycles in some parts of the Amazon are being disrupted. Such disruption occurs more frequently during El Niño events.

Context

As population growth continues and the pressures for economic development within the Amazon increase, more forest is cut down and burnt. Changes in the Amazon rainforest have local and global impacts. Eventually the Amazon rainforest could be degraded to become a savanna.

RESPONSE

Assimilation

1. Define the term 'forest dieback'.
2. Outline the global importance of the Amazon rainforest.
3. Briefly explain why agriculture in the Amazon rainforest is increasing.
4. Describe the distribution of deforestation in the Amazon rainforest.
5. Outline how global economic systems impact the Amazon rainforest.
6. Outline *two* feedback loops in the Amazon rainforest.

Evaluation

1. Explain how water cycles and carbon cycles interact in the Amazon rainforest.

   ANSWER PLAN

   - The natural water cycle involves the transfer of water between atmosphere, land, vegetation, rivers, sea and atmosphere.
   - When vegetation (carbon) is intact, water is recycled locally.
   - When vegetation (carbon) is removed, more water exits the area and a higher proportion reaches the ocean.
   - Precipitation levels over the rainforest then decrease.
   - With less rainfall, there is reduced growth of trees (carbon stores), increased tree mortality and less water retained within the area.
   - This may lead to a vicious circle (positive feedback of water reduction and reduced carbon storage).
   - Less water increases the risk of drought and fire, with further mortality of trees (carbon reduction).

2. Explain why rainforest trees may suffer reduced carbon storage capacity as a result of higher atmospheric temperatures.
3. Outline the main physical and human pressures on the Amazon rainforest.
4. Explain (i) how the loss of tropical rainforest can lead to the occurrence of drought and (ii) the possible role of feedback processes in forest dieback.
5. Explain how changes in agricultural practices can affect carbon stores in the Amazon rainforest.
6. Analyse the causes and consequences of forest dieback.
7. Examine the impact of natural changes in the carbon and water cycles in the Amazon rainforest.

Extension

1. To study the interactions among Amazon land use, forests and climate in relation to tipping points, visit: **https://doi.org/10.1098/rstb.2007.0036**
2. The Met Office has produced materials on ecosystem feedbacks from carbon and water cycle changes at: **https://www.metlink.org/climate/ipcc-updates-for-a-level-geography/carbon-water-vegetation-feedbacks/**

Coral reefs and climate change

Tim Bayliss considers how symbiotic relationships between oceans, climate and biodiversity are changing by focusing on the global importance of coral reefs, their vulnerabilities to climate change and other threats, and the imperative to ensure their protection.

Oceans have long been viewed in practical terms – as a source of food and mineral resources, a dumping ground for waste and, not least, as international highways. Yet life on earth originated in the seas, and the oceans continue to boast incredible biodiversity. Furthermore, oceans are increasingly understood to be major carbon stores and crucial regulators of global climate, air quality and weather systems.

However, in a contemporary era of increasing awareness of climate change, there is no certainty as to how the symbiotic relationships between oceans, climate and biodiversity will change in future. For example, the ability of oceans to take up carbon dioxide depends upon how warm or acidic they become, whether ocean circulation patterns change and what happens to the organisms that trap carbon in their bodies and are then buried on the sea floor. Remember, oceans take decades to heat up and cool down – a time lag suggesting great uncertainty as to the long-term effect of their contemporary soaking up of heat associated with the enhanced greenhouse effect.

In order to illustrate the nature, significance and scope of these changing symbiotic relationships, this article focuses on the 'rainforests of the sea' – coral reefs. The aim is to appreciate their global importance, understand their vulnerabilities and outline the imperative to ensure their protection.

Coral reefs and their deterioration

Ocean biodiversity is not uniformly distributed. For example, one third of all marine species are found in coral reefs. Despite covering only a fraction of the ocean floor, reefs form some of the richest and most diverse ecosystems on earth.

Coral reefs are rocky ridges formed by the hard exoskeletons of millions of tiny coral animals (polyps). The majority of reefs are found within tropical and subtropical waters (between 30° north and 30° south latitudes), with over 90% in the so-called Indo-Pacific region (Figure 1). They require very specific environmental conditions in order to thrive (Table 1). Most reefs are several million years old and have both practical and aesthetic value. For example, they form a natural barrier to protect the mainland from coastal erosion, storm surges and less frequent but

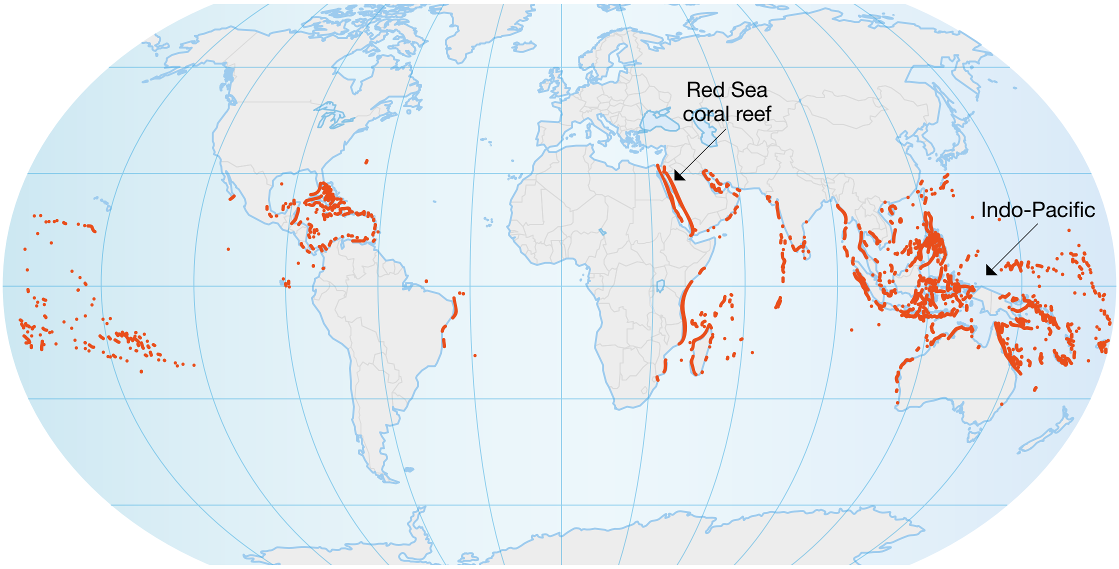


Figure 1 *Global distribution of coral reefs*

potentially much more devastating tsunamis. They store carbon in the form of calcium carbonate, offer a rich source of food (fish), and support algae and sponges with valuable medicinal qualities. However, it is perhaps their stunning beauty and tourist potential that best capture the imagination.

The threats to coral reefs

Half a billion people rely on coral reefs for their food security and livelihoods, yet these are one of the world's most threatened and endangered natural ecosystems. Vulnerabilities include both pollution and physical damage. However, it is climate change associated with acidification and highly destructive thermal stress-induced bleaching which is of most concern (Figure 2).

When carbon dioxide is absorbed in the ocean, it reacts with seawater to increase acidity – dissolving calcium carbonate corals. Bleaching is also highly destructive. In the past 30 years alone, half of the world's corals are thought to have died and many scientists predict that only 10% of reefs can survive past 2050, even if the aspirational target limits set by the 2015 Paris Climate Conference are met. Certainly, limiting global warming to 1.5°C above pre-industrial levels will be 'essential' to give coral reefs a chance at survival. Furthermore, the importance of NGOs (such as the Coral Reef Alliance and the Ocean Agency) leading projects to protect this vital global ecosystem cannot be underestimated.

Coral reef bleaching

Corals get their brilliant colours from tiny plant-like algae (zooxanthellae) that live in their tissues. However, warming ocean temperatures cause 'thermal stress', ejecting the algae and so leaving the white 'bleached' skeleton.

The scale of destructive bleaching has been increasing steadily in the last four decades, from 8% in the 1980s to 31% in 2016. Professor Nick Graham, chair in marine ecology at Lancaster University, expresses this unequivocally:

> All coral reef regions of the world are now experiencing more frequent severe coral bleaching events. Critically, the time between bleaching events is now as short as six years, which is insufficient for full recovery of coral cover on damaged reefs.

Figure 3 shows the bleached Red Sea coral reef off Dahab in Egypt. While it can recover, it will die in the longer term if the algae are not reabsorbed.

The Red Sea coral reef

Threats facing the Red Sea coral reef are indicative of coral reef deterioration across the globe. Some scientists describe it as facing an immediate crisis owing to persistent pollution: land-based

Table 1 *Ideal environmental conditions for the development of coral reefs*

Condition	Effect on coral
Acidity	Corals require high levels of alkalinity (pH 8.2). Increasing acidity (through increased absorption of carbon dioxide) stunts coral growth and can kill it.
Clear water	Corals thrive in clear, unpolluted water. Sediment reduces light and clogs feeding structures.
Salinity	Corals require salinity close to that of seawater – hence gaps in reef development at the mouths of rivers.
Sunlight and shallow water	Corals feed on algae. Sunlight is needed for photosynthesis of the algae – hence corals' restricted growth below 25 m in depth.
Submersion	Exposure to air in the intertidal zone kills coral. Consequently, corals' upward growth is limited to the level of the lowest (neap) tides.
Temperature	Corals require an average ocean temperature above 18°C – ideally between 23°C and 25°C.

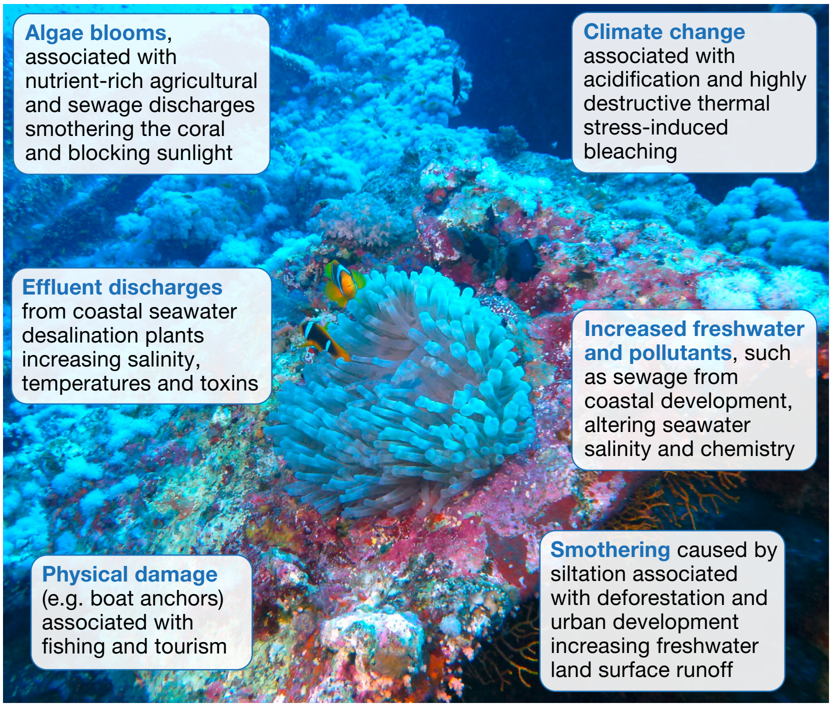
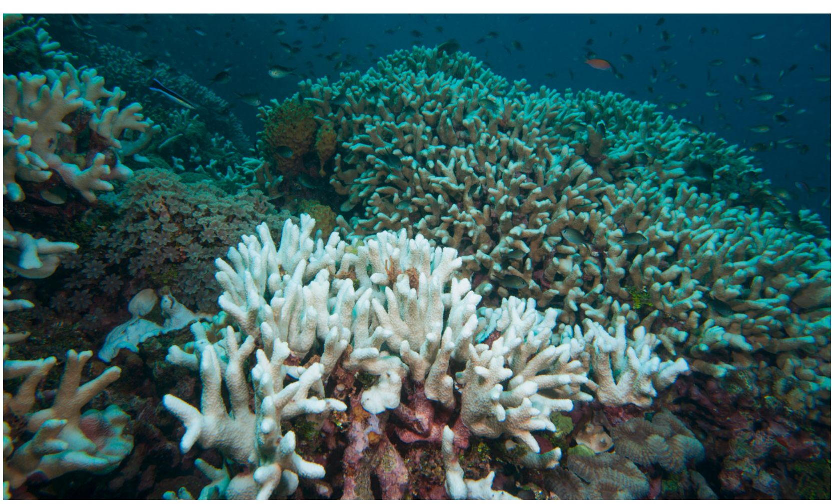


Figure 2 *Coral reef vulnerabilities*

discharges, waste disposal, increased shipping activities carrying chemicals and crude oil, and oil spillage from offshore rigs. Furthermore, there is a widespread perception of insufficient regional political awareness about the importance of maintaining these vital ecosystems. Certainly, tourist descriptions of abundant 'pristine' diving and snorkelling conditions are a thing of the past. This is particularly ironic for Egypt. Tourism here remains a key multi-billion dollar earner of foreign currency, yet the country is also accused of causing much of the destruction (primarily through the continuing disposal of coastal hotel waste, including untreated sewage, into the sea). Beach and water spoliation from offshore oil exploitation is also endemic owing to seepage and spills from ageing oil rigs. Much of the Red Sea dolphin population has migrated southwards as a result.

Figure 3 *Coral reef bleaching*



The United Nations Environment Programme's recent appraisal of Red Sea coral reefs and marine life makes for worrying reading:

> The major threats to the marine environment of the Red Sea and Gulf of Aden are related to land-based activities. These include urbanisation and coastal development... industries including power and desalination plants and refineries, recreation and tourism, waste water treatment facilities, power plants, coastal mining and quarrying activities, oil bunkering and habitat modification such as the filling and conversion of wetlands.

Red Sea management initiatives include proactive partnerships, such as the International Union for Conservation of Nature (IUCN) working with local tour operators and the international travel company Kuoni, monitoring changes in the coral reef, and lobbying for governmental action such as widening the number of marine protected areas in the region. Marine parks show tangible improvement in reef conditions, as do the funding of reef managers and training of dive leaders in sustainable operations. However, the scope for widespread regulation (including prohibition) of fishing, collecting wildlife, scuba dive vessel anchoring and waste discharge is clear, as is the potential for further conservation and/or reintroduction of threatened coral species.

Conclusion

Coral reefs form some of the richest and most diverse ecosystems on earth, with both aesthetic and practical value. Yet destructive fishing, coastal development and pollution are threatening more than half of known coral reefs. This rises to 75% when thermal stress associated with climate change is added to the mix. Left unchecked, 90% of all reefs could be lost by 2050! The scope of local protection initiatives, such as IUCN-supported marine protection in the Red Sea, needs to be widened urgently to include more effective local and regional pollution control. However, climate change leading to acidification and coral bleaching represents the greatest threat of all. If further evidence is required to illustrate the imperative of contemporary political, technological and collective personal initiatives to combat climate change, the potential loss of almost all of these invaluable and beautiful 'rainforests of the sea' within your lifetime is worth contemplating. TE

REVIEW

Key points

- Oceans boast incredible biodiversity. They are increasingly understood to be major carbon stores and crucial regulators of global climate, air quality and weather systems.
- Coral reefs are rocky ridges formed by hard exo-skeletons of millions of tiny coral animals (polyps).
- One third of all marine species are found in coral reefs, forming some of the richest and most diverse ecosystems on earth.
- Half a billion people rely on coral reefs for their food security and livelihoods, yet these are one of the world's most threatened and endangered natural ecosystems.
- Ocean acidification and thermal stress-induced bleaching have killed half of the world's corals over the past 30 years, and only 10% of reefs may survive beyond 2050.
- Limiting global warming to 1.5°C above pre-industrial levels will be 'essential' to give coral reefs a chance at survival.
- The International Union for Conservation of Nature is proactive in the marine protection of Red Sea corals threatened by pollution, tourism and habitat modification.

Pause for thought

- Consider what could and should be done (if anything) to avoid significant coral reef deterioration in your lifetime.
- Consider how mechanisms of the 2015 Paris climate deal may secure, or not, future prospects for coral reefs globally.
- Why might politicians, oil companies and environmentalists hold mixed views as to the fate of Red Sea corals?

Context

- This article seeks to illustrate the nature, significance and scope of changing symbiotic relationships between oceans, climate and biodiversity by focusing solely on coral reefs. Consider the validity of this approach.
- The Red Sea exemplar invites evaluation, demanding perspective far beyond marine environmentalism. Should resource security and the geopolitics of energy, for example, also be considered?

RESPONSE

Assimilation

1. Define the terms 'acidification', 'biodiversity' and 'symbiotic'.
2. Study Figure 1. Describe the global distribution of coral reefs.
3. Outline reasons why coral reef ecosystems are important.
4. List reasons why coral reefs are 'one of the world's most threatened and endangered natural ecosystems'.
5. Explain the terms 'thermal stress' and 'coral bleaching'.

Evaluation

1. Study Figure 1. Analyse the global distribution of coral reef ecosystems in terms of the key environmental conditions associated with reef development.

   ANSWER PLAN

   - Outline, briefly, the global distribution of coral reefs, stating trends (belts), clusters and named examples.
   - For each of the key environmental conditions (outlined in Table 1), systematically state and describe them prior to explaining links to place (location).
   - Ensure that analysis includes references to latitude, ocean depth and proximity to major land masses.
   - A concluding statement should refer back to the question.

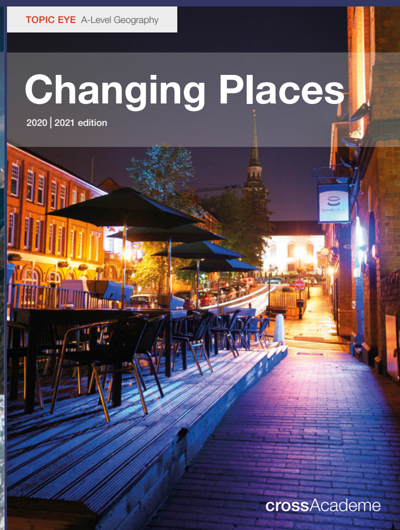
2. 'Only by addressing climate change can coral reef deterioration be addressed.' Critically evaluate this statement, with particular reference to the Red Sea.
3. To what extent do you agree with the contention that coral reef deterioration is an inevitable consequence of economic development?
4. With reference to a named coral reef system you have studied, comment on the management strategies adopted to address the issues associated with its deterioration.

Extension

1. If you want to view coral reefs in high definition and understand their ecology in more detail, a brief video dating from 2017 can be seen at: **www.youtube.com/watch?v=Q9eaEzKKelY**
2. Another brief video, dating from 2007, outlines the context and issues behind the Buccoo Reef Trust Integrated Watershed and Coastal Area Management (IWCAM) Project in Tobago. Further investigation now of this famous Caribbean reef would allow you to evaluate the progress and effectiveness of coral reef management initiatives with the benefit of hindsight. Your starting point can be viewed at: **www.youtube.com/watch?v=5JTrfXLDZLQ**
3. Information on Red Sea coral reefs and their management can be found at:
   - **www.iucn.org/content/keeping-colour-red-sea-coral-0**

TOPIC EYE A-Level Geography

2020 | 2021 titles



Contributors

David Redfern (Editor)
Phil Banks
Tim Bayliss
Garrett Nagle
Rebecca Priest

Systems & Landscapes

- ‘Hothouse Earth’ and climate change
- Feedback mechanisms in coastal landscapes
- Glacier Bay, Alaska – a remote glacial landscape wilderness
- Amazonian carbon and water cycles
- Coral reefs and climate change

Changing Places

- The impact of tourism on Upper Wharfedale
- The representation of ‘place’ in the arts
- Gentrification – Birmingham’s Jewellery Quarter becomes a hipster hotspot
- Studentification – a continuing process of change
- Inequality in London

Natural Hazards

- Crisis in Indonesia, 2018 – a series of tectonic events
- Tropical storms and climate change
- Megacities and the risk of earthquakes
- The threat from Iceland’s volcanoes
- The value of models in hazard response evaluation

Globalisation & Development

- World trade – the new order?
- What is the future of globalisation?
- The UN Sustainable Development Goals
- The rise of ‘modern slavery’
- Development and the increasing tide of plastic

All titles in the 2020 | 2021 series are out now – see contents page for how to order or visit our website at **www.crossacademe.co.uk**.

crossAcademe