The University of Liverpool is the editorial home of the *Biological Sciences Review*. This brochure contains reprints of recent articles written by staff who work in the University, many of whom will be teaching you if you choose to come to Liverpool. The University is proud of its research-connected teaching and the articles will give you some idea of the exciting research currently going on in the Faculty of Science and Engineering – to which you may be able to contribute if you take one of our programmes. We hope you enjoy the articles and if your school or college does not subscribe to the magazine we hope you will bring it to the attention of your librarian.

Liz Sheffield (Chairman of Editors)
It is estimated that there are at least 46,000 pieces of plastic in every square mile of ocean. Liz Sheffield examines what we can do about this huge threat to marine life.

September’s news stories about a seal finally freed from a plastic Frisbee-type flying ring brought plastic pollution back into the spotlight (see https://tinyurl.com/y95p8opf). The upsetting account with a (so far) happy ending was perfect timing to motivate the volunteers on this year’s annual Great British Beach Clean. During beach cleans, which are held all over the world, volunteers collect waste items, thus preventing them from getting into the marine environment. If you watch Sky News, you probably know about sea turtles mistaking plastic bags for their favourite snack of jellyfish, and about microbeads from cosmetics entering the food chain. But do you know what you can do and what scientists are doing to address the plastic pollution problem?

**Biodegradable microbeads**

Microbeads used in the cosmetics industry are usually made from oil products converted into polyethylene or polypropylene, which are both cheap and easy to make. These plastics take hundreds of years to break down in the environment (see Figure 1). A single shower using gel containing microbeads can result in 100,000 plastic particles entering the ocean. The beads are less than 0.5 mm in diameter so are too small to be removed by

<table>
<thead>
<tr>
<th>Item</th>
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<tr>
<td>Paper towels</td>
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<td>Newspaper</td>
<td>6 weeks</td>
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<tr>
<td>Cotton ropes</td>
<td>1–5 months</td>
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<tr>
<td>Apple cores/cardboard boxes</td>
<td>2 months</td>
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<tr>
<td>Waxed milk cartons</td>
<td>3 months</td>
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<tr>
<td>Photodegradable beverage holders</td>
<td>6 months</td>
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<td>Plywood</td>
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<td>Wool socks</td>
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<td>Plastic bags</td>
<td>1–20 y</td>
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<tr>
<td>Tin cans/foam plastic cups</td>
<td>200 y</td>
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<tr>
<td>Aluminium cans</td>
<td>50 y</td>
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<tr>
<td>Disposable nappies/plastic bottles</td>
<td>450 y</td>
</tr>
<tr>
<td>Fishing line</td>
<td>600 y</td>
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</table>

**Figure 1** Average time taken for familiar items of rubbish to degrade in the ocean
What can you do?
Buy paper instead of plastic products (e.g. see www.cottonbudproject.org.uk); recycle.
Tell your friends and family about the issues, post this article or send the following link on social media: https://tinyurl.com/ycm6m8kl
Start a recycling initiative in your school, college, sports club (e.g. see https://tinyurl.com/yab8o4z4)
Sign up to a local beach clean programme (e.g. www.mcsuk.org/beachwatch/user/register and www.nationaltrust.org.uk/features/beach-cleans) or start your own.

Win over the public
A recent paper in the journal Nature Human Behaviour highlighted examples where public pressure has led to policy change, including levies on single-use plastic bags and the ban on the use of plastic microbeads. The authors suggested that such pressure reflects human affection for coasts and oceans and a growing recognition in some members of the public that what we do on land can have extremely detrimental effects at sea. They suggest that more could be done to influence human behaviour.

Ocean plastic pollution poses challenges similar to those of other environmental threats, such as climate change, because the symptoms are often considered remote from the largely land-based causes. This is linked to a perceived lack of urgency to tackle the problems, but the researchers suggest that the public could potentially become motivated if powerful images were carried on everyday products, similar to those already being used on cigarette packaging. Fear and disgust are powerful emotions, however, so the researchers urge caution and suggest any successful campaign would need to make people appreciate the problem and understand how they can play an important part in the solution.

Johnson & Johnson recently phased out the plastic sticks in their cotton buds because they were informed they were not removed by sewage treatment and were building up on beaches. On hearing the news, Dr Sue Kinsey, Senior Pollution Policy Officer of the Marine Conservation Society was delighted but added that we can all do more:

…only the 3Ps — pee, poo and paper — should go down the toilet, everything else should go in the bin.

Sounds like a good slogan for a public lavatory campaign to me.

Further reading
People’s love of the seas could be the key for plastic pollution solution. ScienceDaily News, 18 September 2017: https://tinyurl.com/ybol4tvn
Biodegradable microbeads made from cellulose. ScienceDaily News, 17 June 2017: https://tinyurl.com/y9k3wv5r
Johnson & Johnson ditch plastic cotton buds to save oceans: https://tinyurl.com/yakqnsem

Find out more about our full range of magazines and online archives of back issues at www.hoddereducation.co.uk/magazines

Did you like this article? Tell us what you think.
Hedgehogs are one of Britain’s most popular native mammals. Over the recent past they have been in steep decline. Zoologist Steph Dolben examines the possible causes of this and explains how we can help to safeguard their future.

Hedgehogs are found across most of the world. There are 17 species, and *Erinaceus europaeus* is the European hedgehog, the subject of this article. Hedgehogs live in a variety of different habitats and can thrive in both urban and rural environments. These small mammals are nocturnal. They roam over a wide range at night in search of food (see Box 1) and, during the breeding season, mates. Radio tracking studies show that they have a range of about 10 hectares (24.7 acres) and travel distances up to 2 km in urban areas and up to 3 km in rural environments. They are quick runners, good climbers and adept swimmers.

Hedgehogs are the only mammals in the UK with spines. An adult hedgehog has 5000–7000 sharp spines covering its back and sides. The spines are 2–3 cm long and are made of keratin, the material that forms hair and nails. When a hedgehog is threatened, it contracts two strong muscles on its back to curl into a tight spiky ball, concealing the fleshy, vulnerable parts of its body from predators.

European hedgehogs are active between April and October, and typically hibernate from around November to March (see Box 2). They make different types of nest for different purposes. Daytime nests are used during their active period. Hedgehogs often make several such nests in different sites, as places for them to sleep and shelter during the day. They are usually loosely constructed from grass and leaves. Breeding nests and winter nests are more sturdily built, using medium sized leaves supported by a solid structure such as brambles or piled logs. These nests will be used for several months.

Both male and female hedgehogs have multiple mates during the breeding season, a mating system known as polygynandry. Gestation is around 35 days and they have between four and six hoglets per litter. The young are usually born between May and August.
but in mild summers hedgehogs can have a second litter. Hedgehogs born late have a lower chance of survival because they are unable to put on sufficient biomass to survive hibernation (see Box 2).

In autumn, as the weather starts to get colder and food becomes scarce, hedgehogs start to build their winter nests – hibernacula. They gather leaves, grass, straw or bracken and nest under hedges or sheds, or in piles of wood, compost heaps or old burrows. Then, usually during November, they go into hibernation.

**Declining hedgehog numbers**

In the 1950s one estimate put the numbers of hedgehogs in the UK at 30 million. By 1995 an estimate was 1.55 million. Organisations including the People’s Trust for Endangered Species and the British Hedgehog Preservation Trust have since been gathering information on sightings through volunteer-based wildlife surveys. Their analyses suggest that numbers have again fallen, by as much as 50%, since the turn of the century (see Figure 1). Hedgehogs were named a priority conservation species in the UK in 2017 under the [UK Biodiversity Action Plan](https://www.hoddereducation.co.uk/biologicalsciencesreview). They also have protection under the 1981 Wildlife and Countryside Act, which makes it illegal to catch or trap a hedgehog without a licence. In August 2020, the European hedgehog was added to the IUCN Red List and is now officially classified as vulnerable.

**Causes of decline**

What could be causing hedgehogs to decline so rapidly? Their main natural predators in the UK are badgers – one of the few animals with claws sufficiently robust to tackle a hedgehog in a defensive ball. There is some evidence to suggest that badgers can present a problem. In one study of 30 radio-tagged hedgehogs released into a badger-rich woodland in Oxfordshire, seven were...
**Box 3 Make a tracking tunnel**

Tracking tunnels are a straightforward and effective way of finding out whether hedgehogs are using a habitat. You will need:
- Sheets of lightweight waterproof material (e.g. Correx)
- Strong, waterproof tape
- Heavy-duty utility knife
- Eight paperclips
- Two sheets of A4 paper
- Masking tape
- Vegetable/olive oil
- Powdered charcoal/carbon powder
- Cat or dog food in a shallow feeding bowl

**Construction**
- Cut out four sheets of waterproof material measuring 30 cm wide × 90 cm long.
- Use tape to attach three sheets together to make a triangular tube.
- Cut the remaining sheet to size so that it will slide into the tunnel. Attach two sheets of A4 paper at either end using paperclips.
- Make two wide strips (8 cm each) of masking tape on either side of the A4 sheets, towards the middle of the insert, allowing sufficient space between them for the feeding bowl.
- Make a mixture using 1:1 oil and charcoal powder and spread generously onto the masking tape strips.
- Place insert in the tunnel and add the bowl of food.
- Leave in a position next to a wall or hedge (not out in the open) overnight and check for prints the next day. Repeat for up to 5 days if no tracks are made. Animal prints can be identified using online guides (e.g. https://wildlifetrusts.org/how-identify/identify-tracks)

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eaten by badgers. There is an asymmetric intra-guild predatory relationship – hedgehogs and badgers eat the same food, but when food is scarce the larger animal preys on the smaller. But hedgehogs are still declining in parts of the UK where badger numbers are low.

Hedgehogs carry a range of internal and external parasites, including ticks and fleas, but these do not normally cause serious problems. If a hedgehog is infested with fleas or carries a high burden of ticks, this is usually a sign that it has underlying health problems.

**Habitat loss, damage and fragmentation**

In order to find food, mates and nest areas, hedgehogs need well connected spaces. Hedgerows and copses have been lost to make large fields. The use of pesticides has reduced invertebrate prey. Urban habitat has been lost or fragmented due to large housing developments and road construction. The way we keep our gardens also has an impact. Garden landscaping, paving and decking reduces
the availability of plants and invertebrate prey. Impermeable fences and walls around gardens limit access and connectivity between suitable habitats.

Roads and traffic are a factor contributing to the decline of hedgehogs. Up to 150,000 hedgehogs are killed on roads in Britain every year. Gardens can be hazardous places for hedgehogs and other wildlife they predate (see Box 1). Pesticides used to kill insects, slugs and snails can also be toxic to mammals, birds and amphibians. Hedgehogs are adept swimmers, but they can drown in garden ponds if there is no ramp or shore for them to use to climb back out. Every year thousands of hedgehogs are admitted to rescue centres with horrific, often fatal, injuries caused by lawn mowers, strimmers and netting.

**How we can help**

There are many small changes we can make to help protect hedgehogs:

- **Go wild!** Leave a section of garden untended. Make log piles from dead wood and let brambles flourish.
- **Plant nectar-rich plants that will help attract invertebrates.**
- **Put out some cat, dog or specialist hedgehog food, and drinking water (not milk, as adult hedgehogs are lactose intolerant).**
- **Use alternatives to chemical pest control whenever possible (encouraging hedgehogs into gardens is a natural way of keeping pests at bay).**
- **Create a hedgehog highway. Cut/make holes 13 cm × 13 cm in fences or walls to allow hedgehogs to move freely between neighbouring land and gardens.**
- **Take care when gardening and check the area before using a lawn mower or strimmer.**
- **Check before burning garden waste or bonfires, especially in November when hedgehogs will be making their winter nests. Build bonfires only on the day they will be burned.**
- **Position garden netting 13 cm off the ground and put football nets away when not in use.**
- **Ensure garden ponds have a ramp or shore.**
- **Provide purpose-built hedgehog housing for extra shelter and nesting options.**
- **Support wildlife charities and rescue centres – they rely on monetary donations as well as old newspaper and cat/dog food.**

Organisations such as the Wildlife Trusts, the People’s Trust for Endangered Species and the British Hedgehog Preservation Society fund a range of conservation projects and campaigns for raising awareness. In addition to taking the steps described above, you can help by being involved in surveys, recording and reporting hedgehog sightings online. It is with the help of volunteers and citizen scientists that these organisations can build a better picture of population numbers.

**Topics for discussion**

- How trustworthy are estimates of numbers of any animal (especially nocturnal, solitary animals such as hedgehogs)? Compare and contrast how different organisations working at different times have arrived at the estimates mentioned in this article.
- Should the use of slug pellets be banned? Set up a debate with fellow students role-playing key stakeholders. Suggested roles – agrochemical manufacturer, garden centre owner, prize delphinium grower, hedgehog preservation society member.

**TERMS EXPLAINED**

**UK Biodiversity Action Plan** The UK government’s response to the Convention on Biological Diversity which was initiated at the Rio Earth Summit in 1992. The UK was the first country to produce a national Biodiversity Action Plan, published in 1994, which created action plans for priority species and habitats in the UK that were most under threat so as to support their recovery.

**RESOURCES**

Wilson, E. and Wembridge, D., ‘The state of Britain’s hedgehogs 2018’, People’s Trust for Endangered Species/British Hedgehog Preservation Society: https://tinyurl.com yc49zd26
Hedgehog Street Campaign: www.hedgehogstreet.org
The Mammal Society – a British charity devoted to the research and conservation of British mammals: www.mammal.org.uk
‘British hedgehog now officially classified as vulnerable to extinction’, British Hedgehog Preservation Society: https://tinyurl.com/y2uravfl

Steph Dolben is a zoology graduate who works at the University of Liverpool. She helps with ecological surveys and volunteers at her local wildlife rescue centre. She writes a nature blog on Instagram @nessiesnaturenotebook. In 2019 the University of Liverpool was awarded Bronze accreditation by the British Hedgehog Preservation Society for being a hedgehog friendly campus.
Resistome reservoirs

Antimicrobial resistance is on the increase. Liz Sheffield explains why, and what is being done to make the situation both worse and better.

The idyllic scene above shows reindeer grazing on plants growing in Svalbard. The soil in this remote Arctic location has recently been shown to contain superbugs. Bacteria resistant to one or more antibiotics are everywhere, including in Arctic snow, Antarctic lakes and salad in our supermarkets.

We know they are there from DNA analysis. Antibiotic resistance genes can be detected by DNA sequencing, even if the microorganisms that contain them are difficult to grow in culture, which is often the case. The collective term for these genes is the resistome, and the risk posed by ever more widespread antibiotic-resistant microbes has been recognised as a global challenge (see Figure 1). Authorities in the UK rank the risk alongside that posed to the public by terrorism and pandemic flu.

Figure 1 Resistome reservoirs – habitats of bacteria
Why is resistance on the increase?

As we have seen in previous Updates (‘Bugs be gone’, April 2018: www.hoddereducation.co.uk/bioreviewextras) the two main drivers behind the upsurge of superbugs are environmental use (e.g. in animal-based food production) and inappropriate use in human health. While some parts of the world have taken action to curb the environmental use of antibiotics, others are doing quite the opposite. For example, the Environmental Protection Agency in the USA has recently agreed that up to 195,000 hectares of citrus trees in Florida can be treated with 176,000 kg of the antibiotic tetracycline per year, to combat citrus canker and citrus greening disease. It is estimated that over 9,000 citrus hectares are also treated each year in California.

In most of Europe the supply of antibiotics without prescription is prohibited, but in many European countries and elsewhere in the world they are nevertheless freely available for purchase. While some infections merit the use of antibiotics, many do not, and public understanding of how antibiotics work, how antimicrobial resistance arises, and the risks it poses, leaves much to be desired. It has often been said that physicians prescribe antibiotics inappropriately due to pressure from patients whose poor health is not the result of microbial infection. Numbers of antibiotic prescriptions being issued in England are being monitored, and it was found that simply sending a letter informing GPs that they were in the top 25% of prescribers reduced their antibiotic prescriptions by an average of 3%.

A recent study revealed that many patients felt that obtaining a prescription validated their ill health. Being able to tell the boss, or your school, that you have been prescribed with medication was perceived to lend credibility to the condition. However, many patients are just as happy to leave the healthcare centre without antibiotics but with an official National Health Service form entitled ‘Treating your infection’. These steps are part of the Public Health England campaign to ‘Keep antibiotics working’, to which we should all lend our support.

Activities

1. Become an antibiotic guardian: http://tinyurl.com/yb7u67td
2. Send the above link to all your friends and family on social media and suggest they watch the video on the site and sign up too.
3. Take the antibiotic quiz: http://tinyurl.com/y3e5bwgg and circulate that link (includes simple explanations as well as the quiz).
4. If you live in the UK, compare the prescription of antibiotics by your GP or in your area to the national picture: http://tinyurl.com/yxet5eob

Further reading

‘Study reveals unsettling multidrug antibiotic resistance in remote Arctic soil microbes’. ScienceDaily, 5 Feb 2019: https://tinyurl.com/ya8pdcch

‘How a supermarket salad can transfer antibiotic resistance genes’. SciTech Europa: http://tinyurl.com/yyynng7ah

‘Keep Antibiotics Working’ campaign: www.youtube.com/watch?v=ef4QHUS5760

‘Take your doctor’s advice on antibiotics’, NHS, 16 Nov 2018: https://tinyurl.com/y2brjbj8

‘Antibiotic use on oranges gets Trump administration’s approval’, Center for Biological Diversity, 10 Dec 2018: http://tinyurl.com/y9uynxq8


‘Antibiotics frequently supplied without prescription, global review finds’, Telegraph, 10 July 2018: http://tinyurl.com/y7ck4zy
As in the film *Finding Nemo*, clownfish do live ‘in’ anemones. The fish benefit from the protection afforded by the stinging tentacles of their host, but are themselves unaffected, probably thanks to their thick mucus covering. The anemones gain protection from their own predators, as resident clownfish aggressively defend their hosts. Movements of the fish also stir the water around the anemones, increasing the amount of oxygen that reaches their hosts. And waste products from the fish provide valuable nutrients for the anemone. So the relationship between clownfish and anemones is described as a mutually beneficial symbiosis.

Clownfish reproduction, however, does not reflect the story of the film. Females do lay eggs, and males are assiduous fathers — but that is where similarities between real life and the cartoon end. The first sign that a female is ready to reproduce is when both she and her mate clean their spawning site. The female then deposits a line of eggs onto the cleaned surface, and the male follows closely behind the female, depositing sperm over the eggs. The pair repeat this process.

Real life coral reef biology is rather different from that depicted in the film *Finding Nemo*. Clownfish parental care stops when clownfish eggs hatch, and if a female dies she is quickly replaced. Reproductive biologist Liz Sheffield explains, and outlines some of the challenges faced by coral reef inhabitants.
over and over again, until the 200–1000 eggs in a clutch have been fertilised.

The male then assumes most of the caring responsibilities — he cleans and aerates the eggs. But the female stays nearby to defend the nest aggressively against any predators that threaten the brood. As the embryos develop over the next few days, the male works increasingly hard to ensure their successful development, eventually spending almost all the hours of the day and night tending the eggs. When the eggs hatch, parental care ceases completely. Indeed, the larvae must quickly migrate away from the nest site to avoid being eaten by their parents.

Clownfish hierarchy

Clownfish society is more complicated than simple pairs of males and females. In most locations you will find four or five clownfish associated with each anemone (see Figure 1). Only the biggest two fish reproduce. The largest fish is the female, and she dominates the hierarchy. The next largest fish is the male that will fertilise her eggs. The other two or three smaller fish play no part in reproduction. However, if the female dies, the male undergoes a remarkable transformation over the ensuing few weeks and becomes a fully functional female. The next largest fish in the hierarchy becomes a functional male and this pair enjoy the breeding privileges of the group. This process is called sequential hermaphroditism — in which organisms change from functioning as one sex to another during their lives (see Box 1). This phenomenon is common among plants and invertebrates, but also occurs in several genera of reef fishes.

Coral reef ecosystems

Among the attractions of coral reefs for divers and snorkellers are the stunning diversity of colours of the inhabitants, together with the warm, clear waters. Clownfish are brightly coloured, but the colours of the hard and soft coral animals that form the reefs, and the anemones that live with them, are not those of the animals themselves. To understand what makes coral reefs so colourful we first need to consider the food chains that underpin them.

As we know, the primary source of energy for the vast majority of ecosystems is sunlight. In most familiar ecosystems, sunlight is captured via photosynthesis in green plants and converted into a form that other organisms can use. In terrestrial ecosystems, plants are usually easy to identify — they are free-living, stand-alone structures with which we are all familiar. In coral reef ecosystems, they are less easy to spot.

Much of the photosynthesis carried out in coral reefs occurs inside animals. Soft corals, such as the finger coral shown in Figure 2, have single-celled photosynthetic partners living inside them. These single-celled organisms are algae — a non-scientific term used for a huge collection
of photosynthetic organisms living in wet places that range from massive seaweeds to tiny blue-green bacteria only visible under high magnification in an optical microscope. They all have the green pigment chlorophyll, but many have accessory pigments of oranges, reds or browns, that give their hosts their characteristic colours.

The algae are found inside cells just under the surface of the tentacles of coral animals and anemones, as shown in Figure 3(a). This is another example of a mutually beneficial symbiosis. The algae gain protection from herbivores along with carbon dioxide and nutrients from the animals’ waste products. They are accommodated in structures with large surface areas exposed to sunlight, optimising rates of photosynthesis. This provides the host animals with the oxygen and organic metabolites essential for their survival. Relationships such as these are key to the enormous productivity of coral reef ecosystems.

Warm water can hold less oxygen than cold, and tropical water typically has a low concentration of inorganic ions. This means that there are fewer free-living (planktonic) algae in tropical waters than in temperate marine ecosystems. Although this makes for crystal clear waters, which is great for viewing the inhabitants, it is not great for ecosystem productivity. Without the photosynthesis carried out by the algae living inside the animals, coral reef ecosystems would not survive. This is why coral damage (see Box 2) and coral bleaching — when algae die or are expelled by their hosts, leaving them colourless — are of huge concern to environmental scientists.

**Coral bleaching**

The balance between plant and animal in a coral symbiosis can be disrupted by both biological and environmental factors. If the algae succumb to disease, their pigmentation (and hence colour) is lost and the calcium carbonate skeleton of the animal becomes visible through their transparent tissues (see Figure 4). Since the 1980s it has become
increasingly clear that global warming is causing large-scale coral bleaching. When the thermal tolerance of the symbiosis is exceeded, coral animals react by destroying or expelling their algae. Even without global warming, natural fluctuations in the Earth’s temperature can make things worse. The El Niño event of 1997–98 was blamed for wiping out 16% of the world’s shallow reefs.

Figure 5 Average surface temperature of seas worldwide 1880–2020. The shaded band shows the likely range as there were few accurate measurements taken at the time more than others, and therefore might provide materials we could use to aid reef recovery.

One project involves studying corals in naturally acidified waters. These species could perhaps be transplanted to replace corals wiped out by acidification caused by humans (see Box 2). Other projects involve identifying corals with genes that confer resistance to heat and thence breeding heat-tolerant corals for seeding into reefs affected by global warming, as well as sinking structures into habitats suitable for colonisation by coral animals and thus starting artificial coral reefs. Hopefully these approaches, combined with worldwide agreements to limit fossil fuel use, will mean that future generations can continue to enjoy the beauty and bounty of coral reefs.

Professor Liz Sheffield is chair and plant science editor of Biological Sciences Review. She is Associate Pro-Vice-Chancellor (Education) in the Faculty of Science and Engineering in the University of Liverpool — the first university to teach marine biology in the UK and a centre of excellence for teaching and research in ocean sciences.
During June you may have seen the video that went viral — ‘orangutan filmed trying to fight off digger destroying its jungle home’. The video added to the growing realisation that products used in our daily lives can have devastating effects on habitats thousands of kilometres away. Now Iceland is campaigning for an ‘orangutan friendly Christmas’ but has been denied permission to screen the advert for the campaign, sending the advert viral on social media. Iceland has banned palm oil from its products from the end of 2018 — but is this approach really the answer to saving the orangutan and its habitat?

How do we get palm oil?

Palm oil has been extracted from the fruits of palm trees and used in cooking for at least 5000 years. The Industrial Revolution boosted its use as a lubricant, and the last century saw its increasing use as the basis of cleaning products, cosmetics, foodstuffs from cake to pizza, and biofuel. Demand has soared, and production has kept pace — but not via sustainable harvesting of existing trees. All over Africa and Asia, forests have been cleared, peat burned, and oil palm trees planted to keep up with demand. Indonesia is now the top producer — output increased by over 400% between 1994 and 2004, to over 8.66 million metric tonnes — thanks to an exponential increase in plantations (see Figure 1).

These plantations have replaced natural forest but...
are monocultures — vast tracts of a single species — unsuitable habitat for primates and extremely low in biodiversity. The orangutan population in Borneo was estimated to have halved in just 16 years (1994–2015) and the species is now listed as critically endangered. The greatest losses are in regions where the forest has been cut down or peat burned to make way for plantations. Additional animals are killed by hunters who venture into the forest (for bushmeat and to obtain youngsters for the pet trade), and by farm workers when the apes encroach on agricultural land.

**What is being done?**

One approach, being used in Indonesia, is a moratorium on new licences to grow oil palms. Unfortunately, however, corruption in relation to issuance of licences is rife, illegal forest clearance continues, and ‘evidence’ that this measure is working does not stand up to scientific scrutiny. An alternative approach is to promote the use of sustainable oil palm harvesting. In 2004, the World Wide Fund for Nature set up the Roundtable on Sustainable Palm Oil (RSPO), with industry partners and socio-environmental organisations. Unfortunately, however, recent research concluded that ‘No significant difference was found between certified and non-certified plantations for any of the sustainability metrics...’ and that ‘RSPO principles and criteria are in need of substantial improvement and rigorous enforcement’. Lastly, as advocated by Iceland, is encouragement for consumers to boycott products containing palm oil. While this might look like the best solution, this approach would currently have its own environmental consequences, as oil palms are the world’s most efficient oil-producing plants (see Figure 2).

Research into alternatives to conventional oil production might offer a ray of hope. For example, one yeast is capable of yielding oil on an industrial scale. *Metschnikowia pulcherrima* is highly adaptable, growing well on a huge variety of substrates, including food and agricultural waste, in open tanks (which could be stationed on waste ground or in urban settings which would not sacrifice agricultural land). Here’s hoping research of this type bears fruit soon!

**Further reading**

‘Despite government claims, orangutan populations have not increased’, *ScienceDaily* News, 5 November 2018: [https://tinyurl.com/ybf3ym6y](https://tinyurl.com/ybf3ym6y)

‘“Sustainable palm oil” may not be so sustainable after all’, ABC News Australia: [https://tinyurl.com/yd3558st](https://tinyurl.com/yd3558st)

‘People, palm oil, pulp and planet: four perspectives on Indonesia’s fire-stricken peatlands’, *The Conversation*, 10 August 2017: [https://tinyurl.com/yaps7qp2](https://tinyurl.com/yaps7qp2)

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**Activities**

1. Celebrities and the UK environment minister have praised Iceland’s advert, and many members of the public are urging other supermarkets to ban oil palm-containing products. Debate the issues raised with your family and friends.

2. Look at the media currently providing messages about palm oil [e.g. www.youtube.com/watch?v=pc3z8gepDUg](https://www.youtube.com/watch?v=pc3z8gepDUg) and come up with your own rap, or blog to suggest what people could do to minimise the environmental impact of the products they use.

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**Figure 2** Area of land (hectares) required to produce 1 tonne of different oils

<table>
<thead>
<tr>
<th></th>
<th>Soybean</th>
<th>Sunflower</th>
<th>Rapeseed</th>
<th>Palm</th>
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<td>2</td>
<td>1.43</td>
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Advanced biology

Biological Sciences

Why cells kill themselves
Understanding apoptosis

Making stem cells in the lab
Induced pluripotency and medicine

Key exam skills
How to evaluate and form conclusions

Rocky shore communities
The ecology of a dynamic environment

February 2018     Volume 30     Number 3
It's a hard life on the rocky shore

How organisms cope with a constantly changing environment

Rocky shores provide us with a rare opportunity to view and study an entire natural community. Marine biologist Jack Thomson describes the behavioural and physiological mechanisms that shore-living animals use to deal with the world around them, in particular their individual behavioural coping styles when faced with challenge.

Rocky shores are one of a range of different intertidal habitats that constitute a distinct environment somewhere between entirely marine and entirely terrestrial. The principal feature of a rocky shore is that the substratum is hard and impenetrable to all but a few animal species.

Key words

- Behaviour
- Ecology
- Habitat
- Species
- Community

On rocky shores organisms often find refuge in rock pools. These can be abundant with life and extremely diverse compared with the surrounding exposed rock.

Go online for more discussion about what algae are: www.hoddereducation.co.uk/bioreviewextras (Vol. 30, No. 1)

Rock pools are an interesting distraction on seaside holidays. Shrimp mill about searching for food, periwinkles, limpets and whelks crawl on the rocks, while crabs and fish make the most of shelter, hiding away until night when they can forage more safely. Seaweeds (algae — plants) provide animals with both protection and food. But life on rocky shores can be very hard — and I’m not referring to the rock itself. Acted out under the cover of seaweed are fascinating interactions between organisms and with their environment.
This means that animals are on the surface and, therefore, easily observed by researchers. But, compared with shores with soft sediment — sands and muds where animals can bury themselves — there are few opportunities for animals to escape from harsh environments, predators or competitors. The composition of the communities that are found on a rocky shore reflects how these organisms cope with both biotic (other organisms) and abiotic (physical and chemical) challenges.

**The tides**

The shore is dominated by environmental rhythms. The day–night cycle has an important influence on the ratio of respiration to photosynthesis in plants, and also affects animal physiology. The production of the hormone melatonin in fish and some invertebrates varies depending on the availability of light and on the time of day, and this hormone can influence behaviour. Many animals forage at night and thus avoid being seen by predators.

Another distinct rhythm on the shore is the tide — the rise and fall of the height of the sea relative to land, leaving the shore exposed or submerged. The tide rises and falls twice each day (with some unusual exceptions), with a cycle period of 12 hours and 25 minutes. The amplitude of the tide — how high and low the water goes — is largely a result of the gravitational pull of the Sun and Moon. Over the course of a month, as the relative positions of the Moon, Sun and Earth change, the pull of the Moon and Sun on the sea increases to a maximum when the Sun and Moon are aligned (spring tide) and decreases to a minimum when they are not (neap tide) (see Figure 1).

For a certain period each day, intertidal organisms are submerged or exposed, and this varies over the course of the lunar month. Those at the bottom of the shore spend the majority of their day under the water while those at the top may only be submerged for a few minutes. Unless they've found a rock pool or clump of seaweed in which to shelter, exposed animals face rapid and large changes in temperature and risk drying out (desiccation). Even those in rock pools face difficulties as the community in the pool steadily uses up oxygen and the temperature increases on hot, sunny days. The salinity of water in the pool also changes, either increasing as water evaporates or decreasing as freshwater rain falls or runs off the land into the pool. Until the tide returns, these animals are therefore under increasing physiological stress. Some are capable of protecting themselves. For example, periwinkles withdraw into their shell and seal themselves in using a hard operculum, a feature mostly absent in terrestrial snails. Animals must also be able to resist the impact of waves crashing against the rocks. This factor differs between shores, varying with the aspect and gradient of the shore, and with the weather. Some shores have high wave exposure, others are more sheltered.

**Zonation**

Abiotic factors such as the tides limit the extent to which aquatic animals and algae can extend up the shore. Being marine, most of these organisms

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**Terms explained**

- **Community** An assemblage of species living in the same geographical area.
- **Habitat** An ecological area occupied by a particular species.
- **Intertidal** Land between low water and high water tides.
- **Operculum** A tough plate of calcium carbonate used to seal the shell of a gastropod, which prevents water loss and predation.
- **Pheromone** A chemical produced by one animal that alters the behaviour of another.
- **Range** The area over which a particular species is found.
- **Sessile** Fixed in one place.
- **Zonation** The structuring of a community by biotic and abiotic factors into discrete zones consisting of particular species or groups of species.
thrive better closer to low tide, where submersion time is greatest. When submerged they can respire and feed most effectively. Only those animals with physiological adaptations to resist the extremes of the high shore can extend their range into this environment. However, since all of these organisms are competing for limited space, the lower extent of the range of most organisms is defined by biotic factors including competition and predation.

The interplay between physiological tolerance to the environment and behavioural responses to competitors and predators results in zones of discrete groups of species. Each zone hosts those organisms that are best suited to, and best able to compete for, conditions at a particular shore height. Rocky shores provide one of the best-known examples of zonation, and this can often be clearly observed from just a short distance away as regions of different colour running horizontally along the shore. These colour bands are formed by bands of macroalgae — the large seaweeds. The seaweeds most tolerant to desiccation are found at the top, and the least tolerant are at the bottom on the low shore. Brown seaweeds show a conspicuous change in species at different tidal heights. On very exposed shores, where waves can rip them from the rock, seaweeds are replaced by mussels and barnacles, which also form distinct zones.

**Biotic interactions**

The biological interactions between and within species in a community involve a complex interplay between predation, grazing, competition and its inverse, facilitation (see Box 1). On rocky shores, potential competitors may be kept in check by predators, but competition is a major force driving community structure, especially when predators are absent.

Competition comes in many forms but is invariably over resources, such as space, food or mates. In rocky shore rock pools, cracks and crevices are in high demand, especially higher up the shore where submersion time is short. When space has already been taken, newly arriving organisms, such as water-borne larvae, may either fail to find room or may settle on top of other organisms, killing or displacing them.

Shore crabs are among the most motile of common residents on sea shores and generally aren’t restricted to a particular shore height. They synchronise their movements up and down the shore with light and tidal movement. Competition among these animals is often focused around access to food and mates. When crabs come into contact with each other while foraging, they fight over available food and even engage in kleptoparasitism where one crab steals food from the claw of another. Males also compete over access to females, which they sense largely through the presence of sex pheromones in the water. Male crabs then hold on to a female until she is ready to copulate. So large is
Some animals cannot move around so freely, so successfully competing for high quality territory becomes paramount. Beadlet anemones belong to a group of animals called Cnidaria (Cnide from the Greek work for nettle), which includes corals and jellyfish. Anemones may appear sessile but they can move around, usually very slowly. They position themselves in prime spots where, when submerged, they extend their feeding tentacles, embedded with stinging cells, and capture plankton (see Biological Sciences Review, Vol. 30, No. 2, pp. 12–15) or larger animals such as shrimp or fish. Suitable spots with ready access to food brought in by water currents are limited. They may not be submerged frequently enough, or already be colonised by algae or barnacles. So when an anemone is positioned in a good spot, it fights hard to keep it.

Anemones have a hidden arsenal. Lying beneath the feeding tentacles is a separate type of stinging tentacle, used specifically for fighting other anemones. When challenged, they inflate these tentacles with water and strike them down on their opponent, sometimes causing quite severe damage (see top photo and extra resources). Opponents repeatedly strike and sting each other until one cannot take any more and slowly retreats.

The extent to which these anemones fight depends on where on the shore they are found. Those higher up the shore are more likely to be aggressive than those found lower down. This seems counter-intuitive, since positions lower on the shore, where submersion time is longer, are usually held by the most competitive individuals. It may be that, since good, sheltered spots are in even shorter supply higher on the shore than lower down, anemones have to work harder to keep them.

Understanding how communities grow and develop, and how they respond to challenge, is an important component of ecology, and rocky shores provide an excellent example for the amateur and professional. Few other habitats boast such a range of environmental conditions in such a small space, nor have such diversity so clear to see.

Box 1 Facilitation

Individuals of the same or different species often compete for resources such as food and mates. In contrast, ecological facilitation describes positive, beneficial interactions within and between species, which encourage the development of diverse biological communities. For example, the presence of dense aggregations of barnacles on the high shore has been shown to act as a buffer to high temperatures, reducing rock temperature by several degrees Celsius. This in turn enhances the survival chances of other, temperature-sensitive species. An influx of blue mussels into the previously polluted South Docks in Liverpool not only provided a secondary habitat for other organisms but also improved water quality owing to the mussels’ efficiency as filter feeders. This resulted in a dramatic increase in biodiversity over a period of just a few years.
Water wise
Life in dry environments

Teddy bear cactus
Don’t be fooled by one of the common names for this xerophyte. The furry appearance (see A) reflects its covering of sharp spines, which are modified leaves. The spines trap water on the rare occasions when fog envelops the Arizona desert. The spines deter herbivores and also help the plant to spread. Another name for the plant is jumping cholla. While plant parts don’t actually jump, any animal brushing against the cactus risks taking a segment away with them (see B).

Cholla segments are capable of growing into a new plant when they are removed. They owe their impressive tenacity to their backward-facing barbs (see C). Lab tests show that when anchored in a pork shoulder, a single cholla spine can lift a quarter of a kilogram. The barbs are a huge asset to the otherwise needle-like structure of the spines. Each concentrates pressure onto a small area, reducing the amount of force necessary to grind into its unfortunate target — much like slicing with a serrated knife.

Cactus wren
Perched in the cholla is the state bird of Arizona. At 19 cm long and weighing up to half a kilogram, it is the largest wren in the USA. This is the animal equivalent of a xerophyte — an animal that can live without any free water. The bird gains the moisture it needs from cactus fruits and sap, along with the occasional insect. The bird nests in cacti, protected from all but the toughest predator by the formidable cactus spines.

Marram grass
Marram grass is often used to exemplify xerophytes — plants with adaptations that allow them to tolerate dry conditions. The leaves can curl inwards lengthways, thanks to hinge cells (see Figure 1). This reduces the surface area exposed to dry air. The leaves’ outer layer consists of thick-walled packing cells, covered with a thick waxy cuticle, which minimises water loss. The inner surface has deep clefts, protected by ‘hairs’, which trap still air with high water potential, at the base of which lie the stomata. This plant is often referred to as being a coloniser of newly formed sand dunes, but recent research has shown how it actually builds them. As shown in Figure 2, the plant sends roots down into the sand, but it also generates horizontal stem structures. These below-surface stems are called rhizomes (meaning root-bearers) and, as the sand accumulates around them, they both allow the leaves to rise above the surface and give lateral stability to the growing dune. Over the years, the sand builds up around the rhizomes so that older rhizomes are buried deeper and deeper (see Figure 2).

Further reading
Radboud University, ‘Small steps, big leaps — how marram grass builds dunes’: https://tinyurl.com/yyx225o3
Scientists study puncture performance of cactus spines: https://news.illinois.edu/view/6367/719663
‘Flying cactus? 10 terrifying things you must know about jumping cholla’: www.youtube.com/watch?v=p-Qx7WjcwZI

You can download a pdf of this spread to print as a poster at www.hoddereducation.co.uk/bioreviewextras

Figure 1 Diagram of a transverse section of a dehydrated marram grass leaf

Figure 2 A 3-year old marram grass plant

Professor Liz Sheffield, University of Liverpool
Remote control

Liz Sheffield reviews recent advances in deep sea and aerial remote technologies

Over the last few months most of us have accessed information, entertainment and much of our social interaction on a screen. But practical research has not stalled, and scientists able to work remotely have made some particularly exciting progress.

Deep sea life

The research vessel *Falkor* is funded by philanthropy. During the global pandemic, researchers connected with the vessel and her crew remotely from their homes while it surveyed and sampled the deep waters of Eastern Australia using an underwater robot called *SuBastian* that streamed 4K video (see Figure 1). The research team identified new species of fish, snails and sponges. While shallow corals in the Great Barrier Reef region are currently suffering their third mass bleaching event in 5 years, *SuBastian*’s footage revealed no evidence of bleaching in corals living below 80 metres.

The robotic dives of the latest expedition were live-streamed via The Schmidt Ocean Institute’s channel on YouTube and 112 hours of high definition underwater video allowed the researchers to share their knowledge and excitement about the discoveries around the world. They also interacted directly with the public via chat and commentary, finding — as have so many zoos, wildlife parks and museums that live-streamed during the pandemic — a huge appetite for remote interaction with organisms and the natural world.
Detection of death

Oceans cover more than 70% of the Earth’s surface but forests cover more than 30% of the Earth’s land surface and many are difficult or dangerous to investigate directly. People can ‘disappear’ in forested areas and many missing persons have had to be presumed dead. The search for missing bodies usually starts with pedestrian surveys and cadaver dog teams. But when search areas are extensive or the terrain is rough, ground-based searches can be challenging and resource-intensive. Drone-based remote sensing strategies might be the way forward.

The average adult human contains about 2.5 kg of nitrogen, much of which is released and converted into ammonium compounds when the body decomposes. These compounds and the microbes associated with the body (the necrobiome) change the surrounding soil. Nitrogenous compounds in the soil can spike to levels 50 times higher than when fertiliser is added. This influences both the microbes in the soil (the soil microbiome) and plant composition.

Increased leaf nitrogen increases chlorophyll production so the spectral signature of the fluorescence being generated and reflected from the leaves alters. This means that alterations in the canopy of the leaves on trees in the ‘human decomposition island’ of a body can potentially be detected by drones carrying biochemical and infrared thermal sensors.

With trees acting as environmental sentinels, forensic investigators can make decisions that maximise resources and keep search teams safe in conflict zones. Vegetation that is currently considered an obstacle has the potential to become a significant asset in the detection of human remains.

Weblinks

‘First completely remote at-sea science expedition in Australia’s coral sea marine park discovers new corals and possible species never seen before’, Schmidt Ocean Institute, 24 June 2020: https://tinyurl.com/y6f2azab


Body farm website: https://tinyurl.com/yxcn3ywy

Activities

Find out how unique biochemical signatures might allow human remains to be distinguished from those of other animals, and discuss with your fellow students which ecosystems might include scavengers that could perturb plant detection of human remains: ‘Can the leaves of plants help us find buried human remains?’, Science Alert, 4 Sept 2020: https://tinyurl.com/y2t9ynw8

Get involved in a citizen science project: www.citizenscience.org

For example, 41 165 people in 244 cities took part in the City Nature Challenge despite the pandemic this year. Don’t worry if you aren’t good at identifying organisms — download a free app (e.g. iNaturalist seek: www.inaturalist.org/pages/seek_app — which can give you all seven taxonomic ranks of an animal, plant or fungus from kingdom to species from a photo on your mobile).
Leaf cutter ants are considerably more efficient farmers than their human counterparts. Liz Sheffield explains that they have had a lot more practice!

Ants play a dominant role in the majority of terrestrial ecosystems. Throughout the neotropics, leaf cutter ants are the top ‘herbivores’ – they remove more plant material than any other animal group. But they don’t eat their harvest – they take it back to their vast underground nests, cut it into smaller pieces, and feed it to a fungus. The fungus breaks down the material and provides food for the ants and their brood inside the nests. The ants have honed their skills over 60 million years of fungus crop domestication. The farming systems of humans pale in comparison – they emerged only about 10000 years ago.

**Vast, efficient fungus farms**

Fungus farming systems are up to 9 metres deep, covering areas of over 4000 square metres, with entrances up to 80 metres away. Each can contain up to 10 million workers, which can process the same amount of vegetation as a mature cow.

Ants are skilled architects – excavating sophisticated, climate-controlled subterranean growth chambers – and they carefully regulate the nutrients provided for the fungus crop. A team of researchers recently spent over a hundred hours lying on a rainforest floor next to ant nests. Armed only with forceps, they stole tiny pieces of leaves, flowers and fruits from the jaws of ants as they returned from foraging trips. Analysis revealed that the fragments came from hundreds of different rainforest trees and contained a rich blend of protein, carbohydrates and other nutrients including sodium, zinc and magnesium. The nutritional blend targets the specific nutritional requirements of the fungal crop.
Finally, at some point in history, both humans and ants have gone from being hunter-gatherers to discovering the advantages of cultivation. For centuries, most historians and scientists agreed that when early human groups sought food, men hunted and women gathered (which is the case in most present-day hunter-gathering primates). But recently researchers studying a 9000 year old burial site in Peru and re-evaluating other sites have concluded that 30–50% hunters in those times were female.

The complex society that runs each farm is ruled by a single queen, up to 30 mm long, which can live for up to 15 years and lay up to 1000 eggs a day. Her subjects come in different, smaller sizes, and have different roles. Some raise the young, others remove weeds and diseased individuals from the nest, others go out and forage, and soldiers defend the colony.

**What can we learn from ants?**

Over time, leaf cutter ants have adapted their leaf collecting to the needs of the fungus. This is organic farming without the benefits of the technological advances that have helped human farmers. All leaf cutter ants farm a single species of fungus, which, although it keeps things simple, probably wouldn’t suit human tastes. We expect a varied diet, which comes at the cost of many food miles. We have also bred certain characteristics – particular tastes and textures – into our crops. These benefits of domestication result in greater sensitivity of most crops to environmental threats from pests and climatic variables, requiring pesticide use and irrigation. We have weakened our crops in exchange for the right taste and yield, sacrificed efficiency and added to costs (both monetary and environmental), such as fertiliser usage.

Weblinks

‘Early big-game hunters of the Americas were female, researchers suggest’, ScienceDaily, 5 Nov 2020: https://tinyurl.com/y3s9casu.

‘Where are the ants carrying all those leaves?’: https://youtube.com/watch?v=-6oKJ5FGk24

Activities

Read the article ‘Farmer ants could teach us a thing or two’ (Futurity, 5 Nov 2020): https://tinyurl.com/y6hkyz9h (look at the caption for the image and see if you can spot the [not deliberate] error!). Debate with your fellow students where ethics committees should draw the line when considering research proposals to deprive animals of foodstuffs they have collected – ants, prawns, primates?

Read ‘Sainsbury’s Future of Food Report’: https://tinyurl.com/rxprysz. Ponder how defensible your food choices are and consider the issues food suppliers identify as important to the sustainability of their practices.
When conservationists kill

Lionfish are native to reefs in the Pacific Ocean. Since the 1990s, however, these spectacular animals have spread like wildfire through the warmer parts of the Atlantic and Mediterranean. No-one knows how they arrived, but in Florida the suspicion is that they were dumped in the sea by aquarium owners. Lionfish are notorious for eating all the other animals in their aquaria, and they grow quickly. They can reach 45 cm in length and weigh up to 1.3 kilograms. They are voracious predators — a single lionfish on one reef reduced the juvenile reef fish population by 79% in one season. They are also extremely aggressive to fish the same size or even larger than themselves, so drive species they cannot eat into less favourable habitats. This means that lionfish are causing havoc to the food chains in the reefs that they invade. In some locations, so many native fish species have been wiped out that the lionfish have turned into cannibals, and are eating their own juveniles. This makes little impact on their numbers, however, as they are prolific breeders — females can release 15 000 eggs every 3 days.

They also have up to 18 venomous spines that can kill or paralyse any would-be predators (or unwary divers — the venom is unlikely to kill you, but as a fellow diver once told me, if you get stung you will wish you had died!).

So invasive lionfish are an ecological disaster, and conservationists are tackling the problem using a variety of methods. In Florida there is an annual lionfish derby, with a prize for the most lionfish killed. One diver killed more than 3000 of the invaders last summer. Divers are encouraged to obtain a licence to spear or net lionfish in the ‘no-take’ Florida Marine Sanctuary. Because divers cannot penetrate the great depths occupied by some lionfish, a robot has been designed that can recognise and kill lionfish with an electric current. In Honduras, divers are even attempting to train sharks to attack lionfish. Lionfish jewellery is one of the latest developments to encourage people to catch the fish, which are also quite tasty. Lionfish finger anyone?

Liz Sheffield

Go online for weblinks to movies and further reading on lionfish: www.hoddereducation.co.uk/biologicalsciencesreviewextras
Plants form the base of food chains that support almost all animal life. They are also important for removing carbon dioxide from our atmosphere, and for generating oxygen. If you were asked which plants are the most important players in these processes, you might suggest trees, and describe the role played by the tropical and northern forests. However, of the total amount of photosynthesis happening on our planet, only half of it happens on land. The other half takes place in the ocean.

**Photosynthesis at sea**

What is an important plant that grows in the ocean? When asked that question, knowing what terrestrial plants are like, you might think of things with similar structure and scale — seaweeds. But while kelp forests such as that shown above are important ecosystems in some parts of the world, they do not add much to the total amount of photosynthesis that goes on in the sea — seaweeds are responsible for only about 2–3% of the ocean’s photosynthesis. The most important players in the ocean are the microscopic single-celled plants, the free-living members of which are called phytoplankton (from the Greek *phyton*, meaning plant and *planktos*, meaning drifter).

Phytoplankton are tiny. The smallest is a photosynthetic bacterium called *Prochlorococcus*. This single-celled plant is less than 1 µm in diameter, but it is the most numerous photosynthetic organism on Earth (see Figure 1). It is the dominant plant in most of the open ocean.

Somewhat bigger than these bacteria are the many species of flagellates and dinoflagellates (see centrespread). These eukaryotes are typically a few thousandths to a few hundredths of a millimetre in size. At a similar size there are coccolithophores (see Figure 2 and the centrespread). These single-celled marine plants are encased in chalk plates. Their name reflects these plates — *cocco*— comes from the Greek word for berry, used to denote objects that are spherical, *lith*— comes from the Greek for stone, and *-phore* is Greek for ‘bearing’. Over millions of years, as the coccolithophores sink to the seabed, they become compressed into rock and form features such as the white cliffs of Dover.

At the top end of the size range is a group of phytoplankton called the diatoms (see centrespread). These reach sizes of a few hundredths to a tenth of a millimetre. Diatoms are encased in intricate, tough, silica shells. Their name comes from...
from the Greek word for 'cut in two' as they are all formed in two halves (see the junction running around the cell in A in the centrespread). Over millions of years, as diatoms build up on the seabed they form deep deposits. Under some conditions these deposits form oil; under others, the build-up forms diatomaceous earth. Both commodities are harvested and used in a wide range of applications. The uses of diatomaceous earth include use as a filtration aid, mild abrasive (metal polishes and toothpaste), porous support (cat litter) and a stabilising component of dynamite.

Phytoplankton may be small, but they are very numerous. If you scoop up a mug full of seawater next time you are at the beach, you’ve caught about half a million phytoplankton. They are so abundant we can visualise them from space, using satellite-mounted sensors that can detect chlorophyll (see Figure 3). The sensors measure the amount of light from the ocean (or land) in several wavebands (or colours). The concentration of chlorophyll is estimated by looking at the ratios between the different colours. For instance, the light reflected from the ocean shifts from blue to green as the amount of chlorophyll increases. These satellite methods are tested and calibrated against samples collected by oceanographers working on ships at sea.

The challenges of plant growth at sea
Phytoplankton growing in the ocean have problems that terrestrial plants don’t face. In order to grow, all plants need sunlight, nutrients (such as nitrates and phosphates) and carbon dioxide. On land, most plants have leaves in the air, where there is plenty of sunlight and CO₂, and roots in the soil, where there are nutrients. When they die, their organic material decays in the soil and is recycled into nutrients that can be used by other plants.

In the ocean, life for a plant is trickier. Sunlight is absorbed very effectively by water — at a depth of 50 m or so below the sea surface, the amount of light available is less than 1% of the light that hits the sea surface. So phytoplankton can only photosynthesise and grow in the surface few tens of metres of ocean. But the average depth of the ocean is roughly 3.5 km. When phytoplankton die, they sink to great depths. So the recycling of dead organic material occurs hundreds or even thousands of metres away from the sunlit surface waters. Indeed, when we measure nutrients in the ocean (see Figure 4) we find that there are hardly any in the surface water, but a lot much deeper.

Growing roots to reach hundreds of metres, perhaps over a kilometre, down into the ocean bed is physically unfeasible. So how do phytoplankton grow in the surface sunlit ocean, and at the same time acquire the nutrients they need? The answer lies in how the water circulates and mixes. When you pour milk into a cup of coffee, you might stir the drink to get the milk evenly mixed through it. In the ocean, water currents and turbulence stir up the water, which brings the nutrients from the depths up to the sea surface. Without this, nutrients would become concentrated in the bottom of the ocean and plant life in the surface ocean would cease.

Winds and waves at the sea surface, along with tides, can cause turbulence. This is why, in satellite images showing chlorophyll, much of the ocean’s chlorophyll is in the northern Pacific and Atlantic and in the Southern Ocean — places where we frequently get storms (see Figure 3). Along the equator, deep currents bring inorganic ions up to the surface and provide nutrients for the phytoplankton. So phytoplankton growth is intricately linked to the physics of the ocean.

So what about the carbon that plants need to grow? There is plenty of carbon dioxide dissolved in seawater — there is about 50 times more carbon in the ocean than there is in the atmosphere. When phytoplankton grow in the surface sunlit waters, they absorb dissolved carbon from the sea (in the same way that land plants absorb CO₂ from the air). As the ocean surface loses carbon to the phytoplankton it absorbs more from the CO₂ in the atmosphere.

www.hoddereducation.co.uk/biologicalsciencesreview

Figure 1 Coloured transmission electron micrograph of the cyanobacterium Prochlorococcus. The membranes coloured green are thylakoids — similar to the photosynthetic membranes in chloroplasts ×40 000

Figure 2 Coloured scanning electron micrograph of a cocolithophore on the tip of a pin ×400
Figure 3  Satellite image showing chlorophyll. On the land, the tropical and temperate forests are clearly visible in dark green. In the ocean there is abundant chlorophyll in the northern Atlantic and Pacific, in the Southern Ocean near Antarctica, and along the equator — almost all of this ocean chlorophyll is inside microscopic phytoplankton.

Figure 4  Left: an instrument package being deployed into the ocean to collect information. The package is lowered down to the seabed, sending back data including temperature, salt concentration and the amount of chlorophyll in the water. The grey bottles can be snapped shut at different depths, trapping seawater that is then analysed for phytoplankton and nutrient concentrations back aboard the research vessel (right).
Plankton and our climate

The great depths of the ocean are an advantage to us when it comes to the fate of all that carbon absorbed by the phytoplankton. As with the nutrients used by the phytoplankton, the recycling of the carbon contained in phytoplankton happens deep in the ocean. This means that the organic carbon taken downwards by the sinking phytoplankton will not see the atmosphere again for the length of time it takes the ocean circulation to bring that deep water back up to the surface. This is typically a few hundred to a thousand years. So phytoplankton growth causes the ocean to take CO₂ out of the atmosphere, and the sinking dead phytoplankton export that carbon downward and away from the atmosphere. This carbon sink is a key part of how our climate works (see Box 1).

There is one more important player in this story of how microbes in the ocean affect our climate. The phytoplankton are eaten by tiny marine animals called zooplankton (see Figure 5). The zooplankton play two important roles. First, they themselves are eaten by plankton-eating fish (e.g. anchovies, sardines, mackerel, basking sharks) and so they provide a way of getting all that plant material into the rest of the food chain (see Box 2 and the centrespread). Second, and linked to our climate story, the zooplankton are important because they defecate. The faecal pellets released by these tiny animals are made up of densely packaged waste carbon — carbon that was originally part of phytoplankton cells. These dense pellets sink to the deep ocean very quickly — an efficient pathway exporting the carbon away from the atmosphere, as the high speed of sinking means that most of the recycling of the carbon occurs deep in the ocean, well away from the atmosphere.

Understanding how microscopic plants grow in the ocean and how they affect Earth’s climate is one of the big topics that biological oceanographers investigate. What makes oceanography so interesting is that dealing with such big questions is not just biology. To fully understand the plankton and what they do you also need to include the chemistry of ocean nutrient distributions and the physics of ocean circulation and mixing. When we go to sea on our research voyages we work in multi-disciplinary teams, bringing experts in ocean biology, chemistry and physics together to answer some of the most important questions about how our planet works.

Box 1 Phytoplankton and climate change

The growth of phytoplankton is not limited by a lack of CO₂. This means that increasing CO₂ in the atmosphere, which is happening due to climate change, does not make life better for phytoplankton. Instead, their growth is limited by nutrient supply. Over much of the ocean the limiting nutrients tend to be nitrates and phosphates. However, there are significant areas, such as the Southern Ocean around Antarctica, where there is plenty of these nutrients, but iron is the factor that limits phytoplankton growth.

It has been suggested that fertilising the ocean (e.g. by dumping large amounts of iron in the Southern Ocean) could trigger extra phytoplankton growth and remove more CO₂ from the atmosphere, thus helping to solve our global warming problem. But this wouldn’t work. The excess nitrates and phosphates in the Southern Ocean is part of a global circulation of nutrients. Stimulating the use of these nutrients by adding iron simply means that they are not available for phytoplankton growth in other parts of the world. In other words, fertilising one part of the ocean might increase phytoplankton growth there, but the net effect over the entire global ocean will be zero.

Box 2 How much phytoplankton does a fish need?

The answer to this question depends on how many trophic levels there are between the phytoplankton and the fish. For an anchovy, which eats zooplankton, there are two trophic jumps — phytoplankton to zooplankton, and zooplankton to the fish. For a larger predatory fish (such as tuna or shark) there might be four or five trophic jumps as the smaller fish eat the zooplankton, and then themselves get eaten by progressively larger fish (see centrespread). Very roughly, each trophic jump is 10% efficient in transferring organic fuel up to the next level. So an anchovy will need to have consumed about 10 times its mass in zooplankton, which will be based on 100 times its mass in phytoplankton.

Further reading


The Monterey Bay Aquarium Research Institute: www.mbari.org

Earth Observatory, ‘Chlorophyll’: https://tinyurl.com/ybopemn8

‘From tiny plankton to massive tuna: how climate change will affect energy flows in ocean ecosystems’: https://tinyurl.com/ydcefzov
Trophic levels

Most of the life in our oceans relies on energy from the sun. The primary producers — the organisms at the first trophic level — include some of the microscopic aquatic organisms (plankton) shown here in coloured scanning electron micrographs. These photosynthetic members of the plankton are called phytoplankton.

Phytoplankton

A–C are all single-celled phytoplankton and one thing that distinguishes them from each other is their cell coverings. A is a diatom (×1400). The intricate, tough covering of diatom cells is primarily silica. B shows coccolithophores (×1200) — their cells are encased by chalk plates. C shows a dinoflagellate (×665) — protected by plates of armour made of cellulose (when alive, the cell had one flagellum encircling it and another in the groove running from the middle to the posterior). The posterior flagellum drives the cell forward, the girdle flagellum causes the cell to spin on its axis. The net result is that these organisms spin through the water very efficiently — the aquodynamic equivalent of the aerodynamic efficiency of a bullet travelling out of a rifle barrel.

Zooplankton

D is a copepod (×100) — a tiny crustacean animal — a member of the zooplankton. These organisms form the second trophic level — first consumers — which are in turn consumed by larger consumers further along the food chain.

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Professors Jonathan Sharples and Liz Sheffield, University of Liverpool
Starfish supper

Crown of thorns sea stars are voracious consumers of coral. What can we do to protect coral reefs from these predators?

Figure A  Crown of thorns sea star on coral. The animal has grazed the living topmost layer of the coral, leaving behind empty skeletons of calcium carbonate

Coral feeders

Coral reefs around the world face many challenges. Coral bleaching (linked to climate change), pollution and hurricanes all take their toll. Many reef systems in the Indo-Pacific region, including Australia’s Great Barrier Reef, face an additional, biological threat. Each adult crown of thorns sea star – COTS – can consume its own body area of living coral every night (see Figure A). These nocturnal animals can grow to a width of up to a metre, and on average each individual destroys 13 square metres of coral per year.

In an ecosystem in balance, these coral predators would pose little problem, but humans have overfished their predators (see Box 1) and agricultural runoff has provided rich nutrients for their larvae. Booming numbers of COTS have become the major cause of coral death for the already-struggling Great Barrier Reef and recent research has revealed a sinister twist to the story. While corals can recover, it takes time for them to establish – but the COTS can wait. The juvenile stage of COTS is herbivorous. Normally, the juveniles switch from eating algae to consuming coral when around 4 months old. But if coral is not plentiful, the juveniles can survive on algae until they are up to 6.5 years old, and then switch to eating coral – thwarting coral recovery.
Combating COTS

Until recently, the only sure way to eliminate COTS was physical removal and destruction of the animals (see Figure B). Trials of computerised recognition systems combined with robotic devices to deliver toxic solutions started to show promise in 2005. However, recognition accuracy of less than 70%, the need to inject a toxin into every arm of each animal (to prevent regeneration), and the risks posed by toxins to other life forms impeded progress.

In 2014, research showed that a single injection of bovine bile salts—a readily available commercial product obtained from the meat industry—killed COTS. Bile is secreted by the gall bladder of mammals, and assists with the emulsification of lipids in the small intestine. When injected into a sea star, these salts cause tissue damage, which in turn triggers a rapid and powerful immune response. The wave of tissue destruction that follows kills every part of even large sea stars in less than a day. And crucially, extensive research on a range of animals fed on bile-injected COTS showed no ill effects.

Advances in artificial intelligence and robotics have generated a robot than can recognise COTS 99.4% of the time, so we now have a means to tackle this voracious coral enemy that benefits other organisms in the ecosystem.

Box 1 Biological control

Reefs closed to commercial fishing have fewer COTS than those where fishing is allowed. Research shows that a wider range of fish feed on COTS than previously suspected. The development of a genetic marker for COTS allowed researchers to detect COTS DNA in the faeces of a range of reef fish and invertebrates. So, allowing the natural predators of COTS to thrive could help efforts to control outbreaks.

One species suggested as a key predator in the biological control armoury is the harlequin shrimp (see Figure C). These colourful crustaceans are well known for their gruesome sea star ‘farming’ habits. When a harlequin encounters a sea star, it starts by eating the tube feet (which sea stars use to move around, prise open prey, and ‘right’ themselves if flipped over). This immobilises the sea star, which means the shrimp can continue to dine at its leisure. If the sea star detaches a limb, it can regenerate the limb but the shrimp still gets a good meal, and there are reports of harlequins keeping immobilised sea stars alive for several weeks by feeding them, thus maintaining a living larder.

RESOURCES

‘Hidden army: How starfish could build up numbers to attack coral reefs: crown of thorns starfish lie in wait as algae-eating young before attacking coral’, ScienceDaily, 8 April 2020: https://tinyurl.com/y4a4b4cr

‘“Love hormone” has stomach-turning effect in starfish’, ScienceDaily, 31 July 2019: https://tinyurl.com/y4hcfcf9

‘Fish feces reveals which species eat crown-of-thorns: Great Barrier Reef research finds the destructive starfish is eaten more often than thought’, ScienceDaily, 18 May 2020: https://tinyurl.com/yxoha696

‘Sea-star murdering robots are deployed in the Great Barrier Reef’, smithsonianmag.com, 31 August 2018: https://tinyurl.com/yy7nq2x

Are starfish really fish? National Ocean Service: https://tinyurl.com/y5u23ee4

Professor Liz Sheffield, University of Liverpool
The photo above of three weaver ants was taken in the Maliau Basin in Borneo – one of the few relatively untouched rainforests remaining on Earth. Rainforests are hotspots of biodiversity, containing 50% of the Earth’s terrestrial plant and animal species, and most of the animal species are insects. Members of Insecta are more diverse than any other class of animals – scientists have estimated that there may be up to 30 million insect species worldwide.

Weaver ants get their name from the way they build their nests. The ants form a chain with their bodies to bend leaves (see photo below), and then use silk produced by their own larvae to stitch the leaves together to form strong, waterproof nests in the rainforest canopy. They nest in trees but often hunt for small insects on the forest floor, as the ants in the main photo are doing.

Ants, termites, bees and wasps are eusocial insects. They live in colonies with division of labour, meaning that colony members carry out different roles. The single reproductive queen lays eggs that hatch into non-reproductive workers. The workers perform roles such as nest-building, foraging and looking after future generations of eggs and larvae.

Ants and termites are the most abundant animals in tropical forests. Scientists estimate that they make up to 50% of animal biomass in the tropics. Some ants and termites are keystone species – their part in regulating their ecosystem cannot be played by other animals. Termites play a key role in decomposing dead plant material, which contributes to nutrient cycling, and in regulating soil quality by building mounds and tunnelling for nests. Ants have several roles. Some are important predators of other insects, some are scavengers that facilitate nutrient cycles, and others are seed dispersers that regulate plant communities.

Alice Walker is studying for a PhD at the University of Liverpool, focusing on the roles of ants in tropical ecosystems.
Cleaner shrimps

If you were to climb into the mouth of a giant predator, people would think you had a death wish. But some remarkable animals do this on a daily basis. Cleaner shrimps, in the coral reef ecosystems of the world’s oceans, are known for their daredevil eating habits. Along with some other species, including cleaner wrasse, remoras and gobies, cleaner shrimps feed on dead skin and the parasites that plague large fish. This provides nutrients for the shrimps and improves the health of their hosts. This service does not come at a cost, as the host fish don’t prey on the shrimp. Indeed, they provide safety from potential predators. The relationship between cleaner shrimp and other marine life is a classic example of a mutualistic symbiosis — one fish’s problem is another shrimp’s dinner.

Some cleaner shrimps wait in pairs, others congregate in groups and perform a side-to-side ‘rocking dance’ to attract fish to their stations. They then use their mouth parts and the claws on their front legs to pluck items from the surfaces of their hosts, even going so far as to clean out gills while inside the host’s mouth.

The beneficial nature of cleaner shrimps make them a desirable addition to aquaria. They clean a variety of fish, and help keep the environment free of debris. Jacques, from the film Finding Nemo, was the skunk cleaner shrimp responsible for maintaining the tank in the dentist’s office.

Despite their normally do-gooder behaviour, cleaner shrimps have a darker side. For example, males sometimes feed on females during mating season. Large groups of skunk cleaner shrimps can also turn murderous when there is a shortage of food — waiting for their compatriots to moult and shed their shell before killing them while their bodies are fragile. This prevents shrimps from becoming too numerous and starting to feed on the live tissue of their clients. When they do turn to eating live skin instead of parasites, fish start to avoid cleaning stations, thus harming the entire group. So if you are going to try what the diver did in the following movie, I suggest you first make sure the shrimp looks well fed.

www.youtube.com/watch?v=P1JMKPI3_oE

Max Drakeley Biological Sciences Review editorial assistant, University of Liverpool

Further reading

Find out how Pixar strove to achieve scientific accuracy in Finding Nemo and Finding Dory: https://tinyurl.com/y79qra5u

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During the past month, a state of emergency was declared in Florida, USA. Beaches were closed and public health warnings were issued. The culprit was a tiny microorganism called *Karenia brevis*. This member of the phytoplankton — the photosynthetic base of most marine food chains — is not at all good to eat. The cells contain brevetoxin — a compound that blocks channels in cell surface voltage-gated sodium ion membranes and thus prevents nerve transmission. This can cause paralysis and ultimately death in organisms that ingest the toxin.

**Red tides**

When a particular combination of environmental conditions arises, some organisms multiply so rapidly that they dominate the ecosystem. The result is known as a bloom. Algal blooms form in both marine and freshwater ecosystems all over the world. *K. brevis* is an alga, belonging to a group called dinoflagellates. These unicellular organisms have red and brown accessory pigments in addition to chlorophyll in their photosynthetic apparatus, and in species where these pigments are present in quantities sufficient to mask the chlorophyll, dinoflagellate blooms turn the sea red.

Red tides have been reported for many centuries — for example, in records of sixteenth century Spanish explorers and in the Bible — so they are a natural phenomenon. Temperature, salinity, and nutrients at certain levels can cause a massive increase in *K. brevis*.

**Figure 1** Concentrations of *Karenia brevis* recorded 4–11 September 2018 around the coast of Florida

Some microorganisms can grow in such profusion that they turn the sea red. **Liz Sheffield** explains how red tides can be fatal to other marine life and even humans.
Activities

1. Discuss with your classmates the advantage to *Karenia brevis* of possessing red and brown pigments in addition to chlorophyll.

2. Brevetoxin prevents the transmission of nerve impulses by blocking voltage-gated sodium ion channels. Explain how blocking voltage-gated sodium ion channels has this effect.

3. Discuss with your classmates what you might do to control or prevent red tides if you were Florida’s Governor (see first weblink below).

Weblinks

Florida residents clearly believe that their governor shares some of the blame for red tides — do you agree? Washington Post, 18 Sept 2018: [https://tinyurl.com/y9p6uftp](https://tinyurl.com/y9p6uftp)

‘In Redington Shores the counter attack against red tide begins’ (note: this does not explain how to deal with the red tide itself but only its effects). *Tampa Bay Times*, 15 Sept 2018. [https://tinyurl.com/y75smbmc](https://tinyurl.com/y75smbmc)


No one knows the exact combination of factors that triggers this but high temperatures combined with a lack of wind and rainfall usually precede a red tide. This abundance of toxic phytoplankton has devastating effects all the way along the food chain.

When a red tide forms, the first noticeable casualties are fish, which recently washed up onto Redington Beach (see Figure 1) in such numbers that contractors were deployed with machines to pile up and remove truck-loads of the rotting carcasses. More than 5 tonnes of dead fish were removed from Longboat Key this summer. The next corpses to arrive are those of the organisms that eat fish, including sea birds and dolphins. But the casualties don’t stop with carnivores. The recent red tides in Florida have claimed more than 500 turtles and 100 manatees, presumably as a result of ingesting dinoflagellates when feeding on sea grasses. We have only recently started to understand the full risks posed by *K. brevis*.

**Beachgoers beware**

The risk of severe health issues associated with brevetoxin-contaminated fish are so well known that there is a sophisticated array of systems that monitor red tides, test products destined for human consumption and close down fisheries or shellfisheries until the coast is clear. Members of the public who ignore red tide warnings and catch and eat their own-caught fish or shellfish risk paralytic shellfish poisoning (really dinoflagellate poisoning) and even death.

Another problem with red tides arises from aerosols. Asthma sufferers and people with respiratory problems have long been warned against visiting red tide-affected beaches, and many people who encounter red tide sea spray report irritated airways. It has only recently emerged, however, that exposure to aerosols may be much more damaging than anyone suspected. Experiments with rats exposed to brevetoxin have revealed that the neurotoxin is converted into DNA-damaging compounds in their lungs. This implies that other mammals, including ourselves, may risk cancer as a consequence of encountering red tide sea spray. The Florida authorities are taking no chances and closing beaches badly affected by red tides. (Not good news for the author — writing this en route to the Gulf of Mexico!)
Annual rings

Tree trunks expand by laying down new growth on top of the old growth. The innermost tissues of the trunk are the oldest, the outermost layers are the most recent (see Figure A). This means that wood across the diameter of a tree trunk has been laid down throughout the life of the plant. Trees do not grow at a constant rate. In temperate regions, when conditions are favourable (e.g. in the spring and summer), trees grow quickly, creating large cells – ‘earlywood’. During the autumn and winter, growth slows and then stops, forming smaller cells – ‘latewood’. When growth starts again in spring, a distinct line is created in the wood. These lines mark the boundaries between growth rings – annual rings – and the width of the ring provides a good indication of what sort of conditions the tree experienced. This means that very old trees (see Figures B and C) provide a detailed record of the history of environmental conditions where they have lived.

Dendrochronology

(Dendro- Greek – tree; khronos Greek – time) Where tree trunks form growth rings we can get accurate measurements of the age of particular specimens. Using both live and dead specimens to make detailed measurements of the width of rings, researchers have generated master chronologies spanning back over 10,000 years (see Figure D). This kind of cross matching gives the most accurate measurements of the age of trees, and there is no need to cut a tree down to measure growth rings. Instead we can remove a very slim core from the trunk of a living specimen, leaving the tree to seal the wound and carry on growing. In the same way, cores taken from old wooden structures give accurate dates when the trees were felled.

Radiocarbon dating

The wood in a tree trunk locks in place the carbon that was in the air as carbon dioxide when the leaves used it for photosynthesis. So even if there are not clear rings, which is true of trees in the tropics, we can use our knowledge of the decay rate of radioactive isotopes to get a fairly accurate estimate of the age of a tree. Carbon occurs in three natural forms. One of these, radiocarbon – carbon-14, is an isotope that is unstable and weakly radioactive. We know how long 14C takes to decay and the proportion of the carbon in carbon dioxide that is normally 14C, so the amount of 14C left in a sample gives a good indication of how old the sample is. 14C can also reveal events such as nuclear weapons tests. Wood formed in trees around the world still bears the tell-tale traces of such tests (see Figure E), which generated increased 14C in the air.
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