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Biological Sciences review

Environmental Science

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Better together

Insect–plant mutualism

Acacia ants on a bullhorn acacia

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Zoologist Steph Dolben explores some of the different ways organisms interact for mutual benefit, and explains why a life spent together really can be better

Steph Dolben

EXAM LINKS

AQA Survival and response; Populations in ecosystems
OCR A Plant and animal responses; Populations and sustainability
OCR B Plant reproduction; The impact of population increase
Pearson Edexcel A On the wild side
Pearson Edexcel B Sexual reproduction in plants; Changes in ecosystems
WJEC Eduqas Sexual reproduction in plants; Population size and ecosystems

Mutualism is a form of symbiosis, an ecological relationship between organisms of different species, in which both species benefit in some way. It differs from other forms of symbiosis, such as **antagonism** and **commensalism**. Mutualistic relationships are very common in all kingdoms of living organisms. With help from their mutualist partners, organisms can overcome limitations and thrive in unfavourable conditions. Mutualism gives them a competitive advantage and increases **species fitness**.

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Female Agaonid wasps emerging from the fruit of a fig plant

A well-known example includes the relationship between clownfish and sea anemones. Clownfish have a mucus coating on their skin, protecting them from the anemone's sting. This adaptation allows the clownfish to live safely among the anemone's tentacles, providing them with protection from predators. In return the clownfish provides nutrients in the form of waste, and it helps to guard the anemone from predatory fish.

For a relationship to be considered mutualistic, the benefit to both species must outweigh the cost involved in the interaction. Mutualistic relationships can be categorised based on the extent to which the organisms depend on each other. In obligate mutualism there is a strict interdependency between two species, and neither species would survive under natural conditions without the other. In facultative mutualism two species benefit from the interaction, but they could still survive without the other.

TERMS EXPLAINED

Antagonism A symbiotic relationship between two organisms from different species, where one benefits at the expense of another.

Anthropogenic Changes in nature that are caused by humans, either directly or indirectly.

Co-evolution The process of reciprocal evolutionary changes brought about by the interactions between species.

Commensalism A symbiotic relationship between two organisms from different species where one species benefits but the other neither benefits nor is harmed.

Keystone species A species of exceptional importance in maintaining the species diversity of its ecosystem. When that species is removed, the structure of the ecosystem is significantly altered and can sometimes fail.

Pheromone A chemical substance produced by an animal that influences the behaviour of another individual of the same species.

Sessile Permantly attached, not free moving.

Species fitness The ability of a species to survive and reproduce in its environment.

The key to plant survival

Plants are involved in many types of mutualistic interaction with a diverse range of organisms, including bacteria, fungi and animals. These interactions are incredibly important to the survival of plants. Plants are largely **sessile** organisms, so face challenges when reproducing without some kind of assistance, be it from the wind, rain or animals. Plants rely heavily on insects in particular, because insects can cover long distances.

The three prominent types of insect–plant mutualisms are pollination, seed dispersal and protection. In these interactions the insect provides the plant with some form of service and, in return, receives a reward, such as nutrients or shelter.

Pollination

Flowering plants – angiosperms – make up around 90% of all living plant species on Earth, including food crops. Around 80% of these plants rely on insects for pollination, a process vital for plant reproduction and survival. Pollination involves the transferral of male gametes, inside the pollen grains, from the male part of the plant (anther) to the female part (stigma) to facilitate fertilisation and the development of seeds, from which new plants will grow. Butterflies and bees are not the only insects that help to transfer pollen. Many plants depend on other insects, including beetles, wasps, flies and moths for pollination.

Most fig plants, for example, would not exist without an obligate mutualism with a special group of wasps, which have been **co-evolving** with fig trees for over 60 million years. There are over 850 species of fig, and they all depend on their wasp partners, known as Agaonid wasps, for pollination. In most cases each type of fig is pollinated by a host-specific species of fig wasp. Each needs the other to complete its life cycle. For example, *Ficus semicordata*, the drooping fig, is only pollinated by *Ceratosolen gravelyi*.

Figs are formed from a structure called a syconium. The inside of the fig contains both male and female parts. When the fig is receptive it starts to change colour and emits scents that attract pollen-laden female wasps. Figs emit their own species-specific scent, ensuring their obligate wasp partner can easily locate and pollinate the host plant.

In exchange for pollination the fig trees provide the wasps with a safe place to lay their eggs and a food source for the larvae when they hatch. Agaonid wasps have an amazing life cycle. They are very short lived, spending their entire larval stage inside the fig syconium – indeed, the males are flightless and never emerge (see Box 1).

Seed dispersal

After pollination and fertilisation, an angiosperm's ovule forms a seed and the ovaries develop into the fruit, which protects the seed. Seeds contain the embryo, which develops into a new plant after seed germination (see pp. 20–21).

Box 1 Fig wasp life cycle

1 A pollen-laden female enters the syconium of an unripe, receptive fig through an opening called the ostiole.
2 The wasp lays its fertilised eggs in some of the flowers in the syconium, and in doing so pollinates the other female flowers. The wasp then dies.
3 The flowers' ovaries containing the larvae form gall-like structures (see Biological Sciences Review Vol. 36, No. 4, pp. 22–25). The pollinated female flowers later form seeds.
4 Male wasps hatch and travel through the syconium to fertilise female wasps. Males then dig escape tunnels for the females and die without leaving the syconium.
5 Mated female wasps emerge from their galls and collect pollen from the now mature male flowers.
6 Pollen-laden females leave the fig through the escape tunnels and fly to another receptive fig tree in search of a syconium in which to lay their eggs.

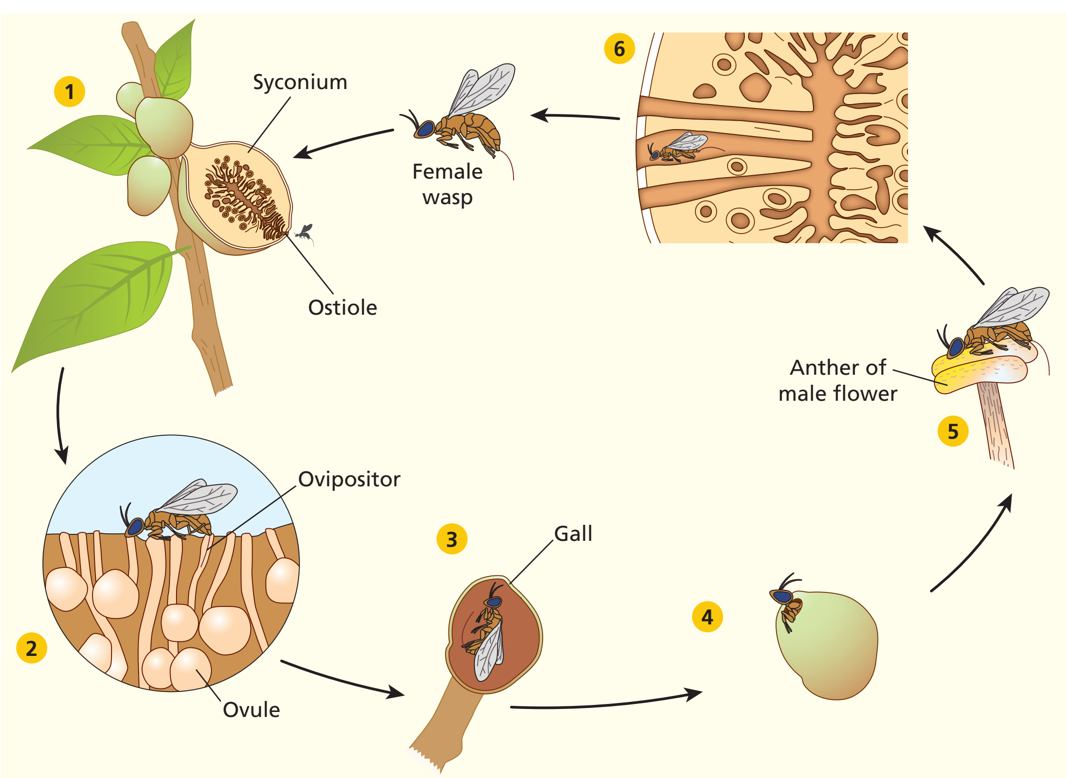

Figure 1.1 Life cycle of a typical fig wasp

Box 2 Elaiosomes

The benefits to myrmecochorous plants are well studied, but less is known about what exactly it is that attracts ants to seeds with elaiosomes, why they carry the entire seed back to their nest, and why they choose to consume the elaiosome instead of the seed itself.

Seeds and elaiosomes have a similar chemical composition. They both contain proteins, carbohydrates and fats. Analysis shows that elaiosomes contain higher concentrations of protein, specific carbohydrates and fatty acids than their seeds. The elaiosome is, therefore, a more nutritious prize.

Scent cues may also have a role in attracting ants to myrmecochorous plants. Elaiosomes contain high concentrations of a fatty acid called oleic acid. The chemical signals emitted by oleic acid are very attractive to ants, and motivate seed-carrying behaviour. Oleic acid is also a major component of the bodies of insects. Some scientists believe that myrmecochorous plants have evolved in such a way that they mimic the chemical signals of insect prey.

In experiments with *Trillium* plants, ants displayed a preference for elaiosomes with higher concentrations of protein and oleic acid, suggesting that it is a combination of both nutritional value and chemical attractants that influences ant dispersal.

Examples of elaiosomes

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Many insects also have a vital role in helping plants to spread their seeds. More than 11 000 plant species are myrmecochorous, meaning they rely on ants for seed dispersal. Examples include violets, primroses, anemones, cyclamens and trilliums.

Ants are opportunistic omnivores, and seeds are an attractive food source. Myrmecochorous plants have an anatomical and biochemical adaptation that allows them to avoid seed predation and exploit ants for dispersal purposes. The seeds of myrmecochorous plants have a lipid-rich appendage, called an elaiosome, which is very attractive to foraging worker ants (see Box 2). The ants carry the elaiosome-bearing seeds back to their nests. Once in the nest the ants detach the elaiosome and feed it to their larvae. The undamaged seed is then deposited in their waste pile. Thus, the development of the elaiosome transfers the reward away from the seed itself.

In return for the provision of this reward the plants benefit by having their seeds dispersed at a

A seed carried by a black garden ant. Each seed has a white appendage, the elaiosome, which ants eat

distance from the parent plant, reducing seedling competition and helping them to colonise new sites. The soil in nest sites is also likely to be rich in nitrates, which helps to increase the chances of successful germination.

Elaiosome-bearing seeds are dispersed by a wide variety of ant species. Myrmecochory is, therefore, an example of non-species-specific, facultative mutualism.

Protection

In defensive insect–plant mutualism, the plant provides food and shelter in return for protection from predators or parasites. An example of this is the relationship between some species of acacia tree and acacia ants. The acacia trees have evolved specialised traits that attract and support ant colonies.

Bullhorn acacia trees, *Vachellia cornigera*, which are native to Mexico and Central America, grow pairs of enlarged, hollow thorns at the base of their leaves. These structures provide shelter and nesting sites for a specific ant species, *Pseudomyrmex ferruginea*, which is notoriously aggressive and has a powerful sting.

As well as providing housing, the acacia provides a ready supply of food for the ant colony. Glands on the leaf stalks – extrafloral nectaries – secrete sugar-rich nectar. The trees also grow tiny detachable tips on the ends of their leaves, which contain proteins, lipids and sugars. These structures have no other known purpose than to provide food for the ants.

In return for food and shelter, these fast and agile ants act as bodyguards, defending the tree against

leaf-eating insects, other animals and competing plants. When ants encounter an invader, they release alarm **pheromones** that cause other ants to rush out of their thorny houses in great numbers and attack.

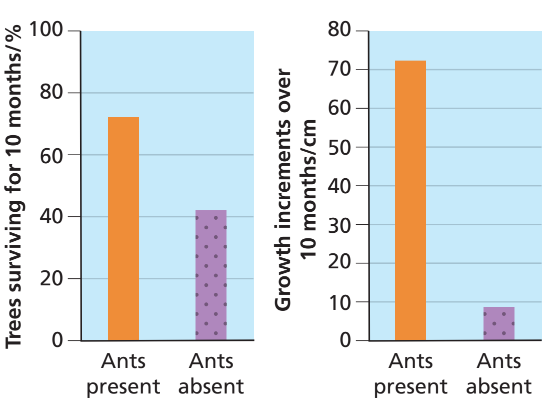
The services provided by the ants have huge benefits for acacia trees. Researchers found that trees with ant populations have higher survival rates and greater growth (see Figure 1).

Conservation considerations

Insects are the most numerous and diverse animals involved in pollination. Besides its ecological importance, pollination also has a high economic value. More than a third of human food is derived from insect-pollinated plants, including 1500 crop species. The estimated economic value of this service is around £274 billion.

Research shows that **anthropogenic** drivers, such as habitat loss, overhunting, climate change and the introduction of invasive species, could potentially cause the breakdown and collapse of mutualistic networks. For example, climate warming is causing some plants to flower earlier than when their insect pollinators start to emerge. Co-extinction is a major concern, especially in obligate relationships, where a decrease in the population of one species directly lowers the population size of the dependent partner.

The benefits of mutualism reach further than the organisms that are directly involved in the interaction. Mutualism benefits the wider ecosystem. Many of the organisms involved are **keystone species**. Fig trees are an example, providing an abundant, year-round supply of food for thousands of animal species. The disruption and breakdown of mutualisms can, therefore, have potentially catastrophic effects on biodiversity.



Source: Redrawn from Janzen, D. H. (1966) 'Coevolution of Mutualism Between Ants and Acacias in Central America.' *Evolution* Vol. 20, No. 3, pp. 249–75.

Figure 1 The effect of ant presence over 10 months on acacia tree survival and growth

Topics for discussion

- Cheating is common in mutualistic relationships. Can you find some plant and insect examples of this?
- What other key role does oleic acid have in the behaviour of ants?
- What other adaptive traits have insects and plants evolved that facilitate mutualism?

RESOURCES

Open University – the unique relationship between the fig and the fig wasp:
https://tinyurl.com/fig-fig-wasp

National Geographic – bullhorn acacia in symbiosis with ants:
https://tinyurl.com/bullhorn-acacia

KEY POINTS

- Mutualism is a form of symbiosis between two species, increasing their fitness.
- Mutualistic interactions include protection, reproduction and nutrition.
- Mutualistic symbionts often have elaborate life cycles.
- Co-extinction due to climate change is a major concern.

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Plant growth

Plant growth regulators (PGRs) occur naturally, but both the regulators and their inhibitors can also be synthesised for commercial applications

What are PGRs?

Compounds that modify the physiological processes, growth and/or development of plants are called plant growth regulators (PGRs). Important PGRs include the following:

- Abscisic acid – regulates leaf drop and seed dormancy, and plays an important role in stomatal opening/closing.
- Auxins – control growth through cell elongation and by stimulating cell differentiation. They move downward only, and act differently depending on the part of the plant to which they are applied.
- Cytokinins – promote cell division and cell enlargement, and the transport of amino acids and nutrients. They are involved in branching, and stimulate the initiation of buds.
- Ethene – promotes senescence and maturity (for example, during fruit ripening). It increases root growth and root hair formation and, in conjunction with jasmonic acid, plays an important role in plant defence responses.
- Gibberellins – control cell elongation and division in shoots. They stimulate the synthesis of RNA and proteins, and are also involved in regulating dormancy.

Gibberellins

The discovery of gibberellins can be traced back to nineteenth-century Japan, when excessive seedling elongation and infertility in rice was found to be the result of fungal infection. Because the disease reduced yield, farmers named it *bakanae* ('foolish seedling'). Nowadays, the disease is easily prevented by treating rice seeds with fungicide before sowing, but the discovery of gibberellins, initially from the fungus that causes *bakanae*, has had transformational effects on agriculture.

One of the biggest challenges for growers of cereal crops is summer storms. Just when the crop is mature and ready for harvest, high winds can flatten the plants. This is known as lodging, and makes harvesting almost impossible. To reduce the impact of lodging, dwarf varieties of cereal crops were bred. The shorter the stems, the lower the likely damage caused by high winds. Plant breeders were selecting for dwarf varieties of crop plants before it was recognised that these varieties were making less gibberellin than their taller relatives. Today farmers can control the height of their crops by applying gibberellins or their inhibitors.

A field of wheat that has been lodged – the plants flattened by a summer storm

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Sugar cane is a crop where farmers use the stems, rather than leaves or seeds. Application of gibberellin to the crop causes the plants to make longer stems – thus increasing the yield of sugar, but also increasing the risk of lodging. Paclobutrazol is a synthetic PGR that inhibits the synthesis of gibberellin. Therefore, if plants are at risk of growing too tall, farmers can apply it to limit growth. This PGR is commonly used to restrict the vegetative growth of tomatoes and peppers, thus increasing the formation of fruits and seeds.

When you buy a plant, you cannot know whether it has been treated with PGRs (for example, to keep the plants compact and save the supplier from having to repot). This is why some ornamentals can look very different after a few months, when the effects of the PGR treatment have worn off.

Cabbage plants: untreated (left) and treated (right) with gibberellin

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regulators

Malt easer

Malt is known as 'the soul of beer', with the process of malting dating back over 4000 years. The process starts with steeping. Barley grains (see Figure 1) are immersed in water, breaking their dormancy. Intake of water triggers the embryo to produce gibberellin. This travels to the stored protein (aleurone) layer around the seed, starting the production of hydrolytic enzymes. Amylase hydrolyses the stored starch to maltose, which maltase then hydrolyses to glucose. This soluble sugar passes into the embryo, fuelling its growth.

The malting process typically takes 4–6 days and results in 'green malt'. As you will guess from Figure 1, however, the process can be sped up by the application of gibberellin to the barley – and that is exactly what maltsters in industry do when time is money. Yields from 'low-vigour' (but tasty) grains are also higher after treatment with gibberellin.

The final step in the malting process is kilning. The green malt is heated to kill the seedling that would otherwise consume all of the starch reserves needed by the brewer. Drying further reduces the moisture content and prepares the malt for the distinctive colour and flavour development needed by brewers in the next steps of the brewing process.

Maltesers have centres of malted milk – malted barley mixed with wheat flour and milk powder – and were ranked in a YouGov poll as the most popular confectionery in the UK in 2020. Advertisements in the 1930s claimed that the centre is one-seventh as 'fattening' as ordinary chocolate centres, which led marketing executives to suggest that the chocolates were beneficial for weight loss.


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Barley grains that have germinated and are ready for malting

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The popular flavour in the centre of Maltesers is provided by malted barley

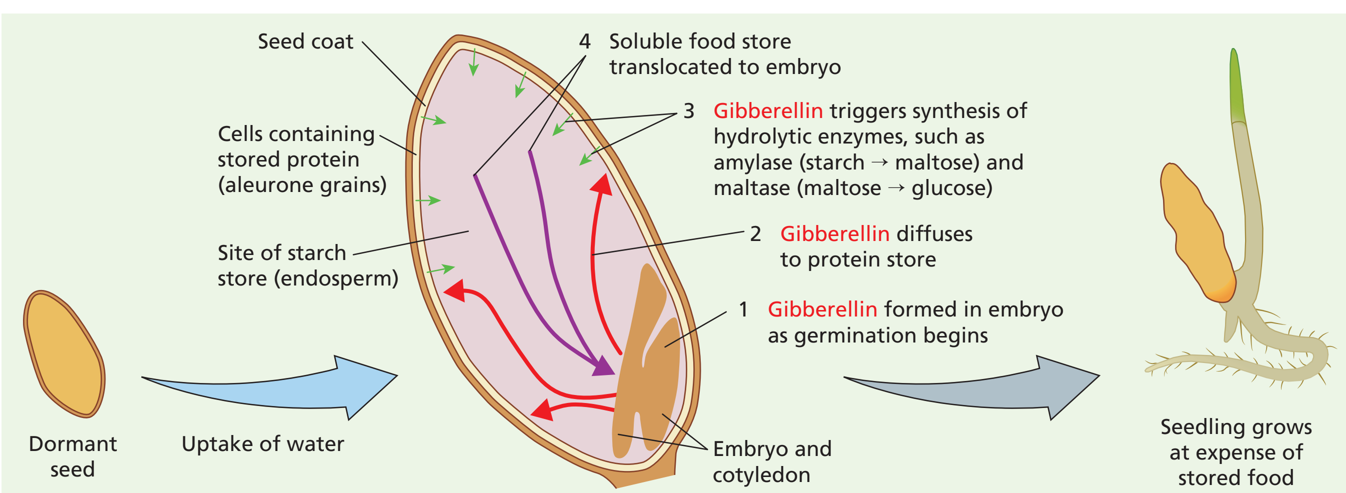

Figure 1 Barley seed germination

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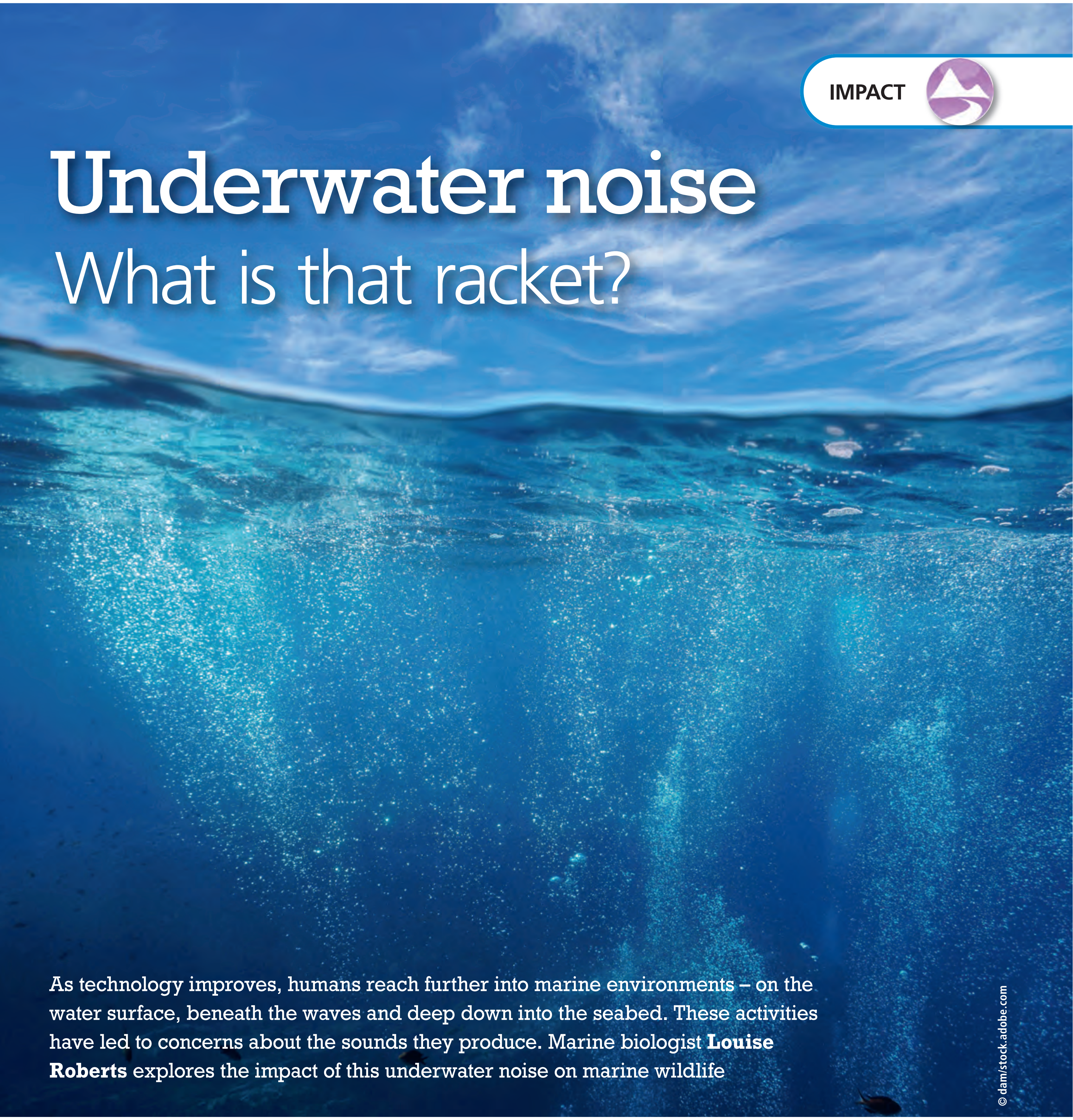

Underwater noise

What is that racket?

As technology improves, humans reach further into marine environments – on the water surface, beneath the waves and deep down into the seabed. These activities have led to concerns about the sounds they produce. Marine biologist Louise Roberts explores the impact of this underwater noise on marine wildlife

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Humans undertake many activities in the marine environment, recreationally, commercially and industrially. Underwater sounds are produced by ships and boats, by fishing activities, by gas, oil and renewable energy acquisition, and even on a small scale when we swim and go scuba diving (see Figure 1).

The construction of offshore platforms, such as for oil and gas, is particularly noisy. In order to build a platform at sea (e.g. to support a wind turbine) the platform must be anchored to the seabed. One way to do this is to hammer long cylindrical piles – often tens of metres wide – into the seabed. Each hammer blow produces a sound in the water column and vibration in the seabed. Construction events may take weeks or months.

Other sounds are more continuous, such as the hum of a boat engine. Different sizes of boats – used for fishing, recreational activities and exploration – produce sounds of varying frequencies, amplitudes and durations.

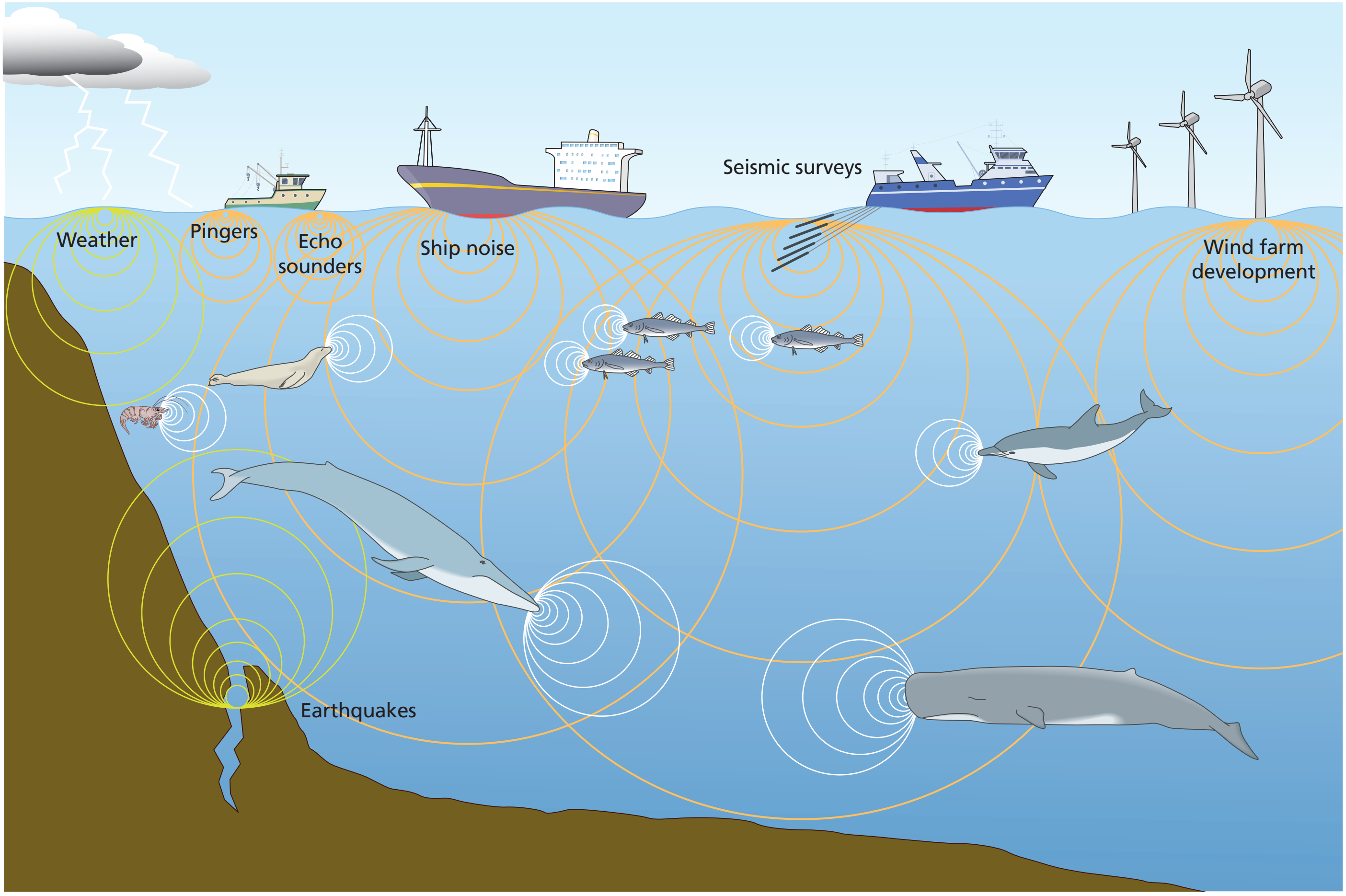

Figure 1 Sources of underwater noise from human activities and biological sounds in the marine environment

Workboats surround the construction of an offshore platform

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TERMS EXPLAINED

Anthropogenic Generated by human activity.

Chemical cue A chemical stimulus that promotes or triggers a biological response.

Hearing sensitivity and frequency range Measures of how sensitive an animal is to sound, and the frequency range (Hz) of the sounds that it can detect. Humans can hear from around 20 Hz to 20 000 Hz.

Quadrat A square frame used in ecological sampling to mark a standard unit of area, within which biological features can be counted or characterised.

Soundscape/vibroscape The pattern of sounds or vibrations in a landscape/environment.

Sound propagation The transmission of sound waves through a medium, such as water or air.

Why is underwater noise a problem?

Many marine organisms use sound in water in the same way that we use sound in air. Sound is used to communicate, to find resources such as food and to navigate. Sounds and vibration travel long distances under water and sound travels five times faster in water than in air. Its velocity is affected by the properties of the water, including temperature, salinity, pressure and depth.

Sounds travel much further than light, which means that aquatic animals can hear across a larger distance than they can see. Some marine mammals and fish actively produce sounds, while others do not (see Box 1). However, scientists have shown that many marine organisms sense a distribution of sounds in a similar way to how we perceive a visual landscape. They call this a **soundscape**, while in the seabed/sediment a **vibroscape** of vibrations may also exist.

The **hearing sensitivity** and **frequency range** of marine animals vary between species. For example, whales have a very wide hearing range, and can detect low-pitched as well as high-pitched sounds, whereas bottom-dwelling fish have a more limited range. Crucially, the hearing range of marine animals often overlaps with the frequency range of **anthropogenic** sounds (see Figure 2). This means that they can detect anthropogenic noise, which may then affect them.

Effects of anthropogenic noise

For chemical pollutants the amount – dose – of the chemical dictates the severity of an animal's response. A high dose may be lethal, while a lower dose may cause disorientation. The same is true for underwater noise. The impact range of a noise source varies with the **sound propagation** conditions, together with the properties of the noisy activity (for example, its duration and repetition). We can predict these using mathematical models to estimate noise levels at a particular distance. The dose of sound an animal receives also depends on its hearing capabilities, and on its position in relation to the noise source.

Box 1 Natural sounds

There are many different sounds in the underwater world, just as there are in air, although our human ear does not work well under water, so we sometimes forget this.

Natural sounds are produced by physical events, such as waves crashing, bubble movement, water currents and even earthquakes. Animals produce sounds. You might be familiar with whale songs, but fish and invertebrates make sounds too. For example, the Atlantic cod (*Gadus morhua*) produces 'grunts' during courtship, and some shrimp 'snap' when they stun prey.

Coral reefs have so many animal sounds that fish and invertebrate larvae can use sound to locate reefs in which to settle. We can assess whether a reef is healthy or unhealthy just by listening.


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Cod fish produce sounds during courtship

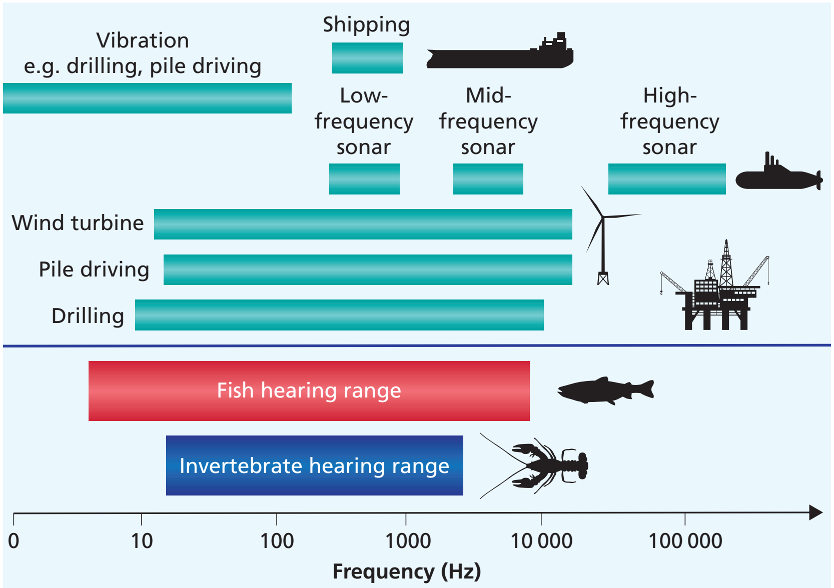


Figure 2 Approximate hearing ranges of fish and invertebrates, compared with the frequencies of anthropogenic noise

Case study – testing whether noise affects a marine animal

One way to test the responses of animals to noise is to undertake experiments in their natural environment. For 3 months in 2018, I worked and lived on Appledore Island in Shoals Archipelago on the east coast of the USA, in a marine laboratory called Shoals Marine Laboratory. It is a fantastic place to undertake scientific work because researchers from all over the world work there. My workday involved snorkelling every day to do my experiments.

Aims and methods

I wanted to know whether hermit crabs (*Pagurus acadianus*) respond to noise. These animals live in areas rich in human activity and its accompanying noise. Hermit crabs are common crustaceans. You can find a related species (*Pagurus bernhardus*) in rockpools in the UK. They have a soft body, which needs protection from damage and predators. To protect the body, the crabs occupy an empty gastropod (marine snail) shell – rather like a mobile home.

I used a **chemical cue**, which we already knew smelt like an empty gastropod shell. I knew that the hermit crabs would not be able to resist this scent, because they are on a constant hunt for a better home. I put the cue inside a small plastic bottle with mesh on top, and used it as bait to attract the crabs.

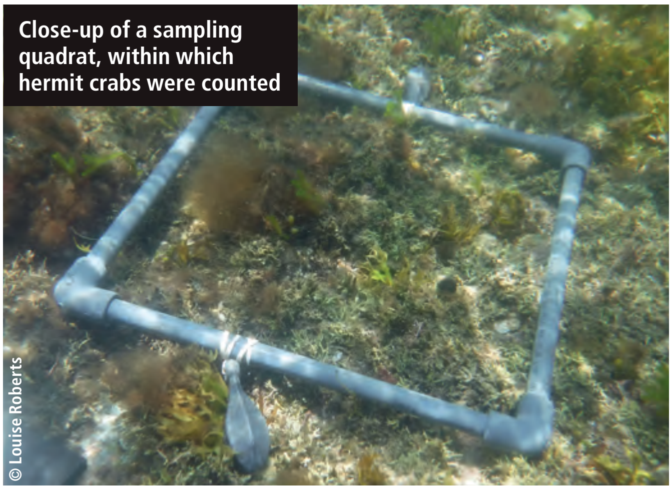
I set up **quadrats** across the seabed, each containing a chemical cue. Next to some of the quadrats I created noise by hammering into the seabed. For control quadrats, the hammering did not take place. At the start of each test I counted the number of crabs inside a quadrat. I did this by diving down to the bottom, counting, then resurfacing to breathe. Then the quadrat was exposed to either noise or silence for 5 minutes. My question was, 'do numbers of hermit crabs differ between the noise and control sites?'. Figure 3 shows the results.

Interpreting the results

Looking at the graph we see that, regardless of whether the quadrat was subsequently noisy or quiet, there were typically one or two crabs at the first count. This was as expected, because there were crabs in the experimental area. After the 5-minute treatment period, regardless of noise or quiet, there were always more crabs on the second count. That made sense, because crabs would be attracted to the chemical cue. But the more important finding was that fewer crabs came to a quadrat when it had been noisy, compared with when it was quiet. The noise deterred some individuals from coming – it prevented them from orientating to, and gathering around, the 'smell' of a new home.

Conclusions

Why might these results have happened? We need more tests to find out. Perhaps the noise affected how the crabs detected the chemical cue, or distracted them from their shell-searching behaviour. Either way, it was clear that the noise had an effect on shell-searching in these crabs – a behaviour that is important for their survival.



Close-up of a sampling quadrat, within which hermit crabs were counted

Acadian hermit crabs that have been attracted to a chemical cue (white container)

Acadian hermit crab (*Pagurus acadianus*)

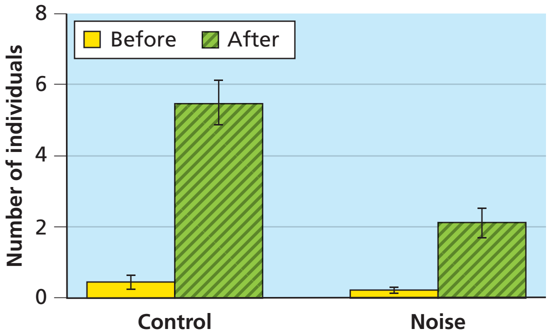


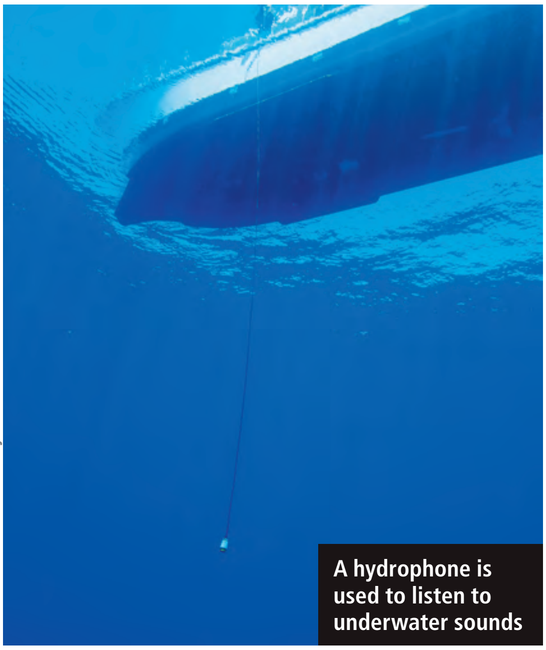
Figure 3 Number of hermit crabs present in quadrats before and after a 5-minute exposure to either silence (control) or noise (mean ± standard error (SE) of the mean, where SE = standard deviation/$\sqrt{n}$; n = 30 quadrats for both).

Table 1 Potential effects of anthropogenic noise exposure on marine organisms

Impact	Effects on individuals	Effects on populations
Trauma to tissues and organs – e.g. gas-filled organs	Injury or death	Mortalities, changes in size and age structure of population
Damage to auditory system	Temporary or permanent hearing loss	Increased mortality risk, leading to reduced abundance, reproduction and growth
Masking of biologically important sounds	Disruption of behaviour – e.g. reduced communication and spawning	Increased mortality risk, leading to reduced abundance, reproduction and growth
Changes in behaviour	Direct behavioural modifications – e.g. avoidance reactions, stress responses	Displacement from preferred habitats, disrupted migration and spawning, reduced growth and reproduction
Changes in physiology	Altered metabolism, slower growth, release of stress hormones	Reduced population growth and reproductive output

The effects of noise upon animals can be categorised according to their severity (see Table 1). Very close to a high-amplitude source, noise may cause immediate or delayed mortality, for example by rupturing tissues. Permanent or temporary hearing loss may be caused by noise when hair cells in the ear are damaged. Further away from the source, animals may be unable to hear other sounds because of the noise, or display behavioural changes, such as leaving the area or cessation of feeding. These effects may be short lived or long lasting.

Scientists use a device called a hydrophone to listen to underwater sounds. Hydrophones contain a ceramic material that responds to changes in pressure, such as those created by sound waves. The response is an electrical signal, which can then be recorded and amplified. The electrical signal is analysed in terms of its amplitude (loudness), frequency (pitch) and pattern over time. See the 'Resources' box for how to build a basic hydrophone.



A hydrophone is used to listen to underwater sounds

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Looking towards an acoustic future

Humans will continue to use the oceans, and there will always be noise to some degree. However, we can mitigate its impacts. First, we need to know the dose of sound that causes a particular response. In the case of marine mammals, for which we have plentiful data, we can then set sound exposure criteria to regulate the level of noise put into the water, ensuring that it is below a damaging level.

To reduce noise in the water, we can change the sources themselves – for example, using quieter boat engines – or we can time our activities to avoid biologically significant places or times, such as avoiding a feeding ground where animals gather. The difficulty is that, for most marine animals (especially fish and invertebrates), we still have no idea how well they hear, and if or how they respond to noise. This means that we cannot set accurate exposure criteria to protect them. With more scientists working in this research field, we need to build up evidence to support the regulation of underwater noise pollution.

RESOURCES

The Discovery of Sound in the Sea (DOSITS) website is written by scientists from all over the world, including the author:
www.dosits.org

Sound and coral reef restoration:
https://www.bbc.co.uk/news/science-environment-59567875

Can we fix ocean noise?
https://tinyurl.com/ocean-noise

How to build a simple hydrophone:
https://tinyurl.com/simple-hydrophone

'Costing the Earth' – sounds in the seas:
https://www.bbc.co.uk/sounds/play/b068w44v

THINGS TO DO

- Visit the websites of the Marine Biological Association and the Marine Conservation Society to learn about the marine environment and how you can help.

Dr Louise Roberts is a lecturer in marine biology at the University of Liverpool. She is interested in how animals use sounds and vibrations, how they hear and produce sounds, and how they respond to anthropogenic changes such as noise.

EVALUATING EXPERIMENTS

How logjams slow the flow

Drought and flooding are becoming more commonplace due to climate change. Logjams – made by beavers or engineered by humans – can hold water on the landscape, providing nature-based solutions and valuable habitats. Environmental engineer Elizabeth Follett explains how her team used flume experiments to find out how water flowing past pieces of wood creates water stores

The frequency and intensity of drought and flooding are increasing due to climate change. One way to address this is to use nature-based solutions, which aim to work with natural processes to change how water is stored.

An engineered logjam is one such measure, which aims to mimic the benefits of beaver dams and naturally generated logjams. As water flows through the wood pieces, an upstream area of slower, deep water is created. This area is referred to as a backwater in engineering and forestry management.

Slowing and storing water upstream of the logjam can help disperse floodwaters over time. If the retention time of the stored water is long enough, this reduces flood damage in downstream communities. The backwater can also increase the amount of water that moves down through the ground and is stored in between soil particles. Increased groundwater

A beaver dam

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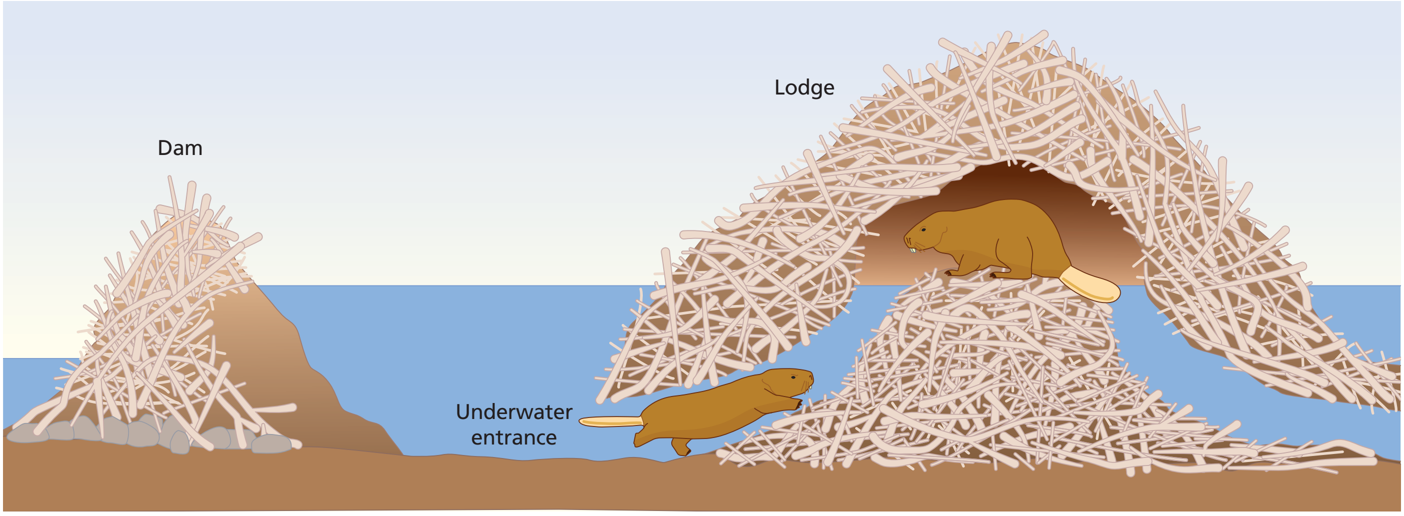

Figure 1 A beaver dam and lodge

storage reduces the impact of drought, and can reduce the amount of floodwater moving downstream, reducing flood impacts on downstream ecosystems.

The installation of engineered logjams also has benefits beyond their impact on drought and flooding. Different logjam designs can be chosen to help trap sediment, which improves downstream water quality. Logjams with a gap between the wood and the channel bed or banks redirect water towards the gap area. This can increase the scouring of sediment locally, creating deeper pools. Pools provide cool, deep areas in which fish can take refuge during the warm summer months, benefiting fish populations. For example, researchers have found increases in the density, survival and production of juvenile steelhead salmon following installation of engineered logjam beaver dam analogues in North America.

Beavers as ecosystem engineers

Beavers are famous for building dams, the longest of which was recorded in Canada at over 500 metres. The backwaters created by their dams (logjams) can be hugely beneficial to other species, but why do beavers create them? The answer lies in their need for a safe place to live. Figure 1 shows why deep water is important to beavers. The underwater entrances and exits to their lodges allow them to evade large predators, and keep their young offspring hidden from view.

First the dam is constructed, then, when the backwater has deepened, the living quarters (lodge) are built. So where do they start? On arrival at a new location with a suitable stream or river, the beavers start by felling trees and saplings. They are able to do this thanks to their powerful jaws and iron-clad teeth.

Their incisors grow continuously, and the front surfaces are strengthened with iron – making them bright orange. This means that the front of the teeth wears more slowly than the back, which makes them self-sharpening. One beaver can fell a 3-metre tree in only 5 minutes. Larger trees are usually tackled by gnawing part-way through the base of the trunk and letting wind and gravity do the rest.

The resulting logs are then dragged to the site of the dam, the base of which is supplemented by stones and mud from the riverbed or bank. As more logs and mud are added, more water is held back, eventually creating a backwater perfect for building a lodge.

Beaver populations are not beneficial everywhere, and the backwaters they create are not always in locations helpful to humans. For example, the ponded water created by beavers can flood farmers' fields. In rural areas of North America, the collapse of beaver dams has occasionally resulted in flooding that has claimed human lives. So how can we achieve the ecosystem benefits of backwaters without involving beavers? First we need to understand how logjams work.

© Peter Hermes Furian/Alamy Stock Photo

A beaver-gnawed tree

A beaver chewing on a branch

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How do logjams create a backwater?

How does water flowing past the wood pieces in a logjam create a backwater? We need to understand the relationship between a logjam's physical structure and its backwater rise. This will allow logjams to be designed that generate a known amount of backwater rise under a given flood condition, and improve the accuracy of modelling approaches for logjams. We hypothesised that groups of logs should act similarly to other groups of solid objects, such as buildings, with momentum loss proportional to the number, size and packing density of the logs and the length of the logjam.

To test our hypothesis, we conducted experiments in an open channel flume, a bit like an indoor river (see Box 1). We cut sticks of a wide range of different sizes (0.23–6.5 cm) and tested 62 different logjams with varying flow rate for a total of 584 cases. We measured the logjam length L, log diameter d, number

Box 1 Modelling logjams

Figure 1.1 shows model logjams in an experimental flume. Flow direction from left to right is indicated by the red arrow. Water depths at the upstream and downstream edges of the jam (H_{up}, H_{exit}) and flow depth far downstream of the jam (H_{down}), equal to the unobstructed flow depth with no jam present, are shown with vertical red lines.

Case A shows an example of a condition for which $H_{exit} = H_{down}$. Here, the water depth upstream of the jam rises to balance the momentum loss within the logjam (see Equation 1.1 below). H_{exit} related to the minimum H_{up} would have been below H_{down}:

$$H_{up}{}^2 - H_{exit}{}^2 - \frac{C_A q^2}{gH_{exit}} = 0 \qquad (1.1)$$

H_{up} is the water depth at the jam upstream edge and H_{exit} is the height of water leaving the jam. The A stands for the solid area perpendicular to the flow per jam volume. The unit discharge q is equal to the volumetric discharge (volume of water flowing past each second) divided by the width of the channel, and $g = 9.8\,\text{m}\,\text{s}^{-2}$ is the gravitational constant. The dimensionless structural parameter

$$C_A = \frac{LC_D a}{(1-\phi)^3}$$

includes the jam length, drag coefficient $C_D = 1$, and two ways of measuring the packing density of the logs. The solid volume fraction is the fraction of solids in the logjam.

For Case B flow recovery extends beyond the region shown by the photo, and therefore $H_{exit} > H_{down}$. Here the water depth upstream of the jam rises to balance the loss of momentum within the logjam and to minimise upstream water depth (see Equation 1.2 below). The water exiting the logjam rises until the upstream water depth reaches the minimum possible value. That is, $\delta H_{up}/\delta H_{exit} = 0$. This gives:

$$H_{up} = \sqrt{3}\left(\frac{C_A q^2}{2g}\right)^{1/3} \qquad (1.2)$$

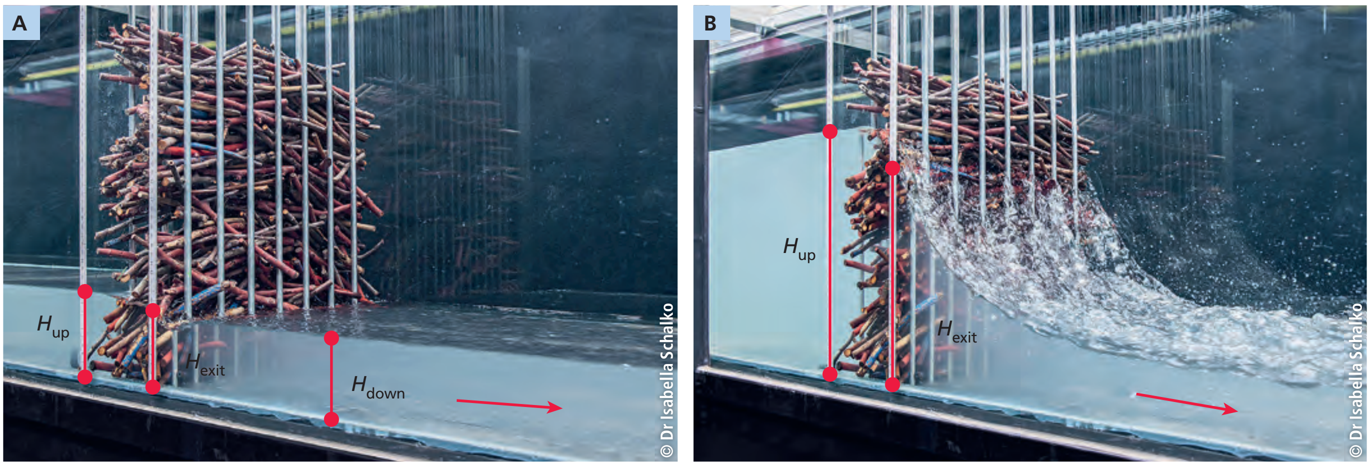

Figure 1.1 Modelling logjams

of logs used and volume of the assembled logjam. Water was let into the flume to flow past the logjam. We measured the change in water depth upstream and downstream of the logjam, and the discharge, or volume of water flowing past a point each second.

We tested the idea that the loss of momentum of water inside the logjam is proportional to the number, size and packing density of the logs, and also the length of the logjam. The change in water depth within the logjam generates a net hydrostatic pressure force, which balances the drag generated by wood pieces. Under the conditions we studied, drag was due to friction between the water and the surface of the wood, impacted by the number, size, and shape of the wood pieces.

For all cases, the momentum loss between the logjam's upstream and downstream edges was proportional to the number, size and packing density of the logs, and the length of the jam. This confirmed our hypothesis that the wood pieces inside the jam would act like other groups of solid objects, so that the drag generation inside the logjam was physically analogous to flow through vegetation stems or groups of buildings.

For some of our experimental cases the depth of water exiting the jam was equal to the water depth far downstream of the jam. This meant that Equation 1.1 (see Box 1) fully explained the backwater rise for these cases. The upstream water depth could be found from our measurements of jam length, log diameter and packing density, and the unobstructed flow depth – which depends on the discharge and channel properties, and is often measured at river gauging stations or can be estimated for ungauged channels.

For some other cases the depth of water exiting the jam rose higher than the depth measured downstream, creating a region of falling water at the downstream edge of the logjam (see case B in Figure 1.1).

RESOURCES

How beavers build dams:
https://tinyurl.com/beaver-dams

Ecosystem experiment demonstrating benefits of natural and simulated beaver dams to a threatened population of steelhead salmon:
https://www.nature.com/articles/srep28581

The data collected from our experiments are publicly available on Zenodo:
https://zenodo.org/records/2640932

Information on natural flood management measures for the UK:
https://tinyurl.com/UK-flood-measures

Why is falling water sometimes present?

We wondered why the exit depth was increased in some cases. What would have happened if the falling water were not present? If this had occurred, the water exiting the logjam would have moved very quickly. This would have generated a large amount of drag as the water flowed past the wood pieces, and so the change in water depth within the jam would have needed to be large in order to balance the drag loss. In this case, the upstream water depth would have been higher than the water depth we actually observed in the experiments.

Using our experimental observations, we demonstrated that the observed upstream water depth in our experiments was the minimum possible value for that jam and flow condition. We also investigated other possible explanations – for example, that exit depth increased to compensate for friction generated by turbulence generation and air bubble entrainment in the region of falling water at the end of the jam. But these mechanisms were too small to explain the change.

We showed that the momentum loss inside the jam happens in a similar way to flow through other groups of solid objects (e.g. vegetation and buildings), and that the exit depth adjusts to minimise the increase in upstream water depth. The backwater rise upstream of a logjam can be predicted from unit discharge and the dimensionless structural parameter (see Box 1).

How is this work used in the real world?

Our results are used to improve the accuracy and efficiency of modelling and field studies. The equation relating backwater rise to the logjam length and number, size, and packing density of the logs can be used to represent a logjam in hydraulic flood modelling software. Such models are used in industry to design and assess the performance of flood mitigation schemes.

Our work can also be used to design engineered logjams and plan field measurements of natural logjams. Researchers can measure the length, diameter, and packing density of the logs, or use Equations 1.1 and 1.2 to find the dimensionless structural parameter from measured discharge and backwater rise. This lets researchers compare logjams between different sites with a common structural metric.

A real-world example of a natural flood management site where man-made engineered logjams have been used to temporarily store water is the Two Lads site in the Pennine uplands, North West England. Engineered logjams were put across a decommissioned reservoir that had filled in with sediment. Living willow trees were planted along the logjams to encourage regeneration of the barriers as the willows grew. The relatively flat, wide area allowed the logjams to store the large volumes of water needed to create an impact on flood reduction. Monitoring of the site pre- and post-installation showed an average of 27.3% reduction in the volume of water flowing out of the site after installation of the logjams.

Dr Elizabeth Follett is a Royal Academy of Engineering research fellow in the Department of Civil and Environmental Engineering at the University of Liverpool. She investigates the impact of wood jams and vegetation on water flow and sediment transport.

Liz Sheffield, who made small contributions to this article, is an emeritus professor at the University of Liverpool and chair of editors of Biological Sciences Review.

The photos in Figure 1.1 were provided by **Dr Isabella Schalko**, formerly at Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich.

Flamingos flock together

Building strong relationships with like-minded friends is key to human happiness, but friendship may be just as important for flamingos. Behavioural ecologist Fionnuala McCully explains how information on associations can be used to improve the lives of birds in captivity


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Chilean flamingo

It can be misleading to assume that we know what animals need to be content. Humans often identify with other animals that look and act like us, such as great apes. For less relatable animals, including flamingos, it is harder to guess what makes them comfortable. This lack of understanding can lead to poor welfare in captivity.

By anthropomorphising (attributing human traits to animals), zoos can make decisions on their behalf that create inappropriate conditions. Our aim was to discover what makes flamingo friendships tick, so that we can encourage better social health in zoo-housed populations.

Flamingo society

It is difficult to be lonely when you are a flamingo. Finding solitude is tricky when you live in a massive flock, but this lifestyle does have its advantages. Flock members display together when breeding to aid in mate choice, cooperatively defend their chicks against predators (such as gulls) and support each other in fights.

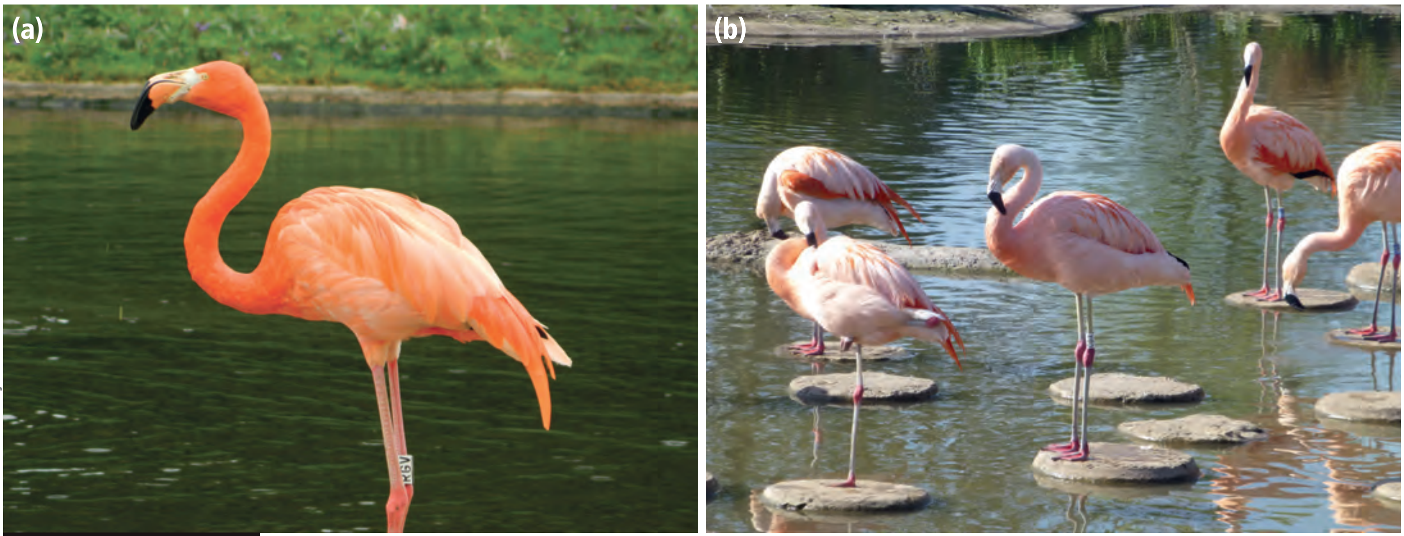
Humans also benefit from having allies when cooperating or navigating conflict. These similarities make it easier for us to imagine what flamingos might need to maintain a healthy social life – perhaps the freedom to associate with friends of their choosing? However, to create an action plan for captive populations, imagination alone is not enough – we need scientific evidence.

Captive flamingo welfare

Four of the six species of flamingo are considered to be either near threatened or vulnerable by the **IUCN**. This means that captive populations of these birds are extremely valuable. If more conservation action is required in the future, captive birds may be used to preserve a species.

Flamingos can live up to 80 years in captivity, and we have a duty of care to ensure their long lives are as content as possible. Perfectly replicating wild conditions is impossible, and so we must explore more realistic ways to provide captive flamingos with a healthy social life.

In 2012 University of Exeter researcher Dr Paul Rose started collecting data from



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© Paul Rose

(a) Caribbean and (b) Chilean flamingos housed at WWT Slimbridge. These are two of the six species of flamingo found globally, and all six can be found at WWT Slimbridge

captive flamingos at the Wildfowl and Wetlands Trust's (WWT) Slimbridge Wetland Centre in Gloucestershire. Paul aimed to improve our understanding of flamingo social behaviour, and use this information to promote their welfare. I was recruited to answer the following questions on the Caribbean and Chilean flamingo flocks:

- Do flamingos form bonds with specific individuals?
- If so, why do they prefer some birds over others?

To address these questions I used **social network** analysis.

Social network analysis

Researchers use social network analysis (SNA) to visualise and explore the structure of social groups. In a social network individuals are represented by '**nodes**', which are linked together by '**edges**' (see Figure 1). SNA can reveal all kinds of information. For example, it can highlight the group's strongest relationships or demonstrate how information or disease travels between nodes.

To build a social network researchers observe which individuals are interacting. For this it is necessary to tell each individual apart – a tall order when working with 250 similar pink birds. Thankfully, Slimbridge's flamingos wear a plastic 'Darvic' leg ring, each printed with a unique code.

Searching for these Darvic rings allowed me to work out which birds were spending time together. However, it was not as simple as spending an afternoon watching flamingos. Ensuring the data were robust took months of observation.

The gambit of the group

All scientific studies rely on assumptions. A key assumption in SNA is 'the gambit of the group'. If two individuals are standing next to one another, they are assumed to be 'associating'. But there is a catch. Imagine that you board a packed bus. You settle next to a stranger and spend your journey

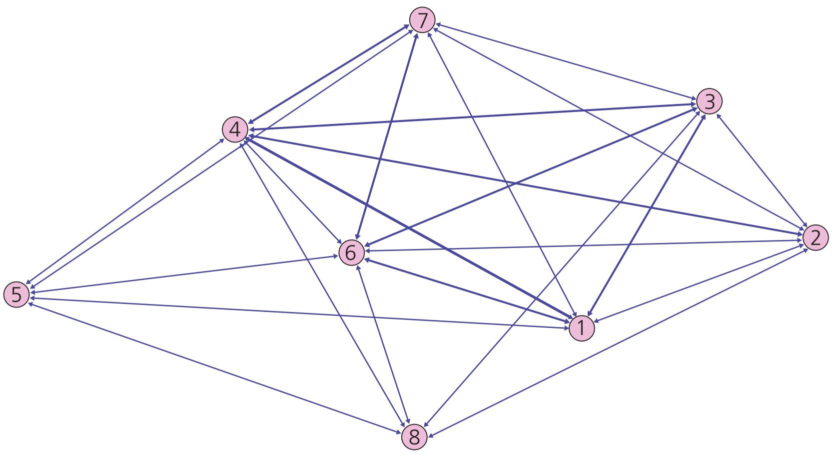


Figure 1 An example of a social network. The 'nodes' (numbered circles) represent individuals, and the 'edges' (lines) represent relationships. The thicker the edge, the stronger the relationship between those two nodes (i.e. the more time those individuals spent in each other's company). The network shape (e.g. edge length) is determined by the data

TERMS EXPLAINED

IUCN The International Union for Conservation of Nature is an organisation working in the field of nature conservation and sustainable use of natural resources. It is involved in data gathering and analysis, research, field projects, advocacy and education.

Social network The relationships within a group of interconnected individuals, which can be visualised to explore social patterns.

Node Representation of an individual in a social network, usually visualised as a shape.

Edge Representation of a relationship within a social network, usually visualised as a line connecting two nodes.

sitting silently side by side. If a social network analyst were to observe you, according to the gambit of the group, your close proximity means you are associating with the stranger. In reality you have no connection at all, and to assume that you are friends is unsound.

So how do we strengthen an assumption? The answer lies in repeated sampling. Seeing two individuals together once is not enough to label them as friends. They must be seen associating many times. Now imagine that you catch that same bus every day, and every day you sit next to the same person. You may build a rapport with one another. If the social network analyst observed you together every day for 4 months, the assumption that you are genuinely friends becomes stronger.

I took photos of the two flamingo flocks four times a day, 4 days a week, for 4 months. When I analysed the resulting 4000 images I focused on birds standing within the association distance of one neck-length. This is within pecking distance, and so suggests an element of trust between the birds.

Over the 4 months I spotted the same birds standing together again and again. Some of them I never found outside of each other's company. According to the gambit of the group, these friendships were the strongest. In contrast, when I rarely saw two specific birds together, I judged their relationship to be weaker. Like strangers on a bus, it may be that they were only recorded together due to chance.

The gambit of the group remains an assumption. Something other than friendship (e.g. shared resources) could be bringing individuals together, but checking hundreds of times makes this explanation less likely. Assumptions are necessary, but researchers should clearly explain the steps they have taken to justify their choices. If they fail to do this, we should be wary of their conclusions.

Flamingo friendships

Once the social networks were determined, they could be used to explore the relationships. Both flocks were very well connected. All of the birds associated with every other member of their

Darvic rings allow identification of the flamingos

© Paul Rose

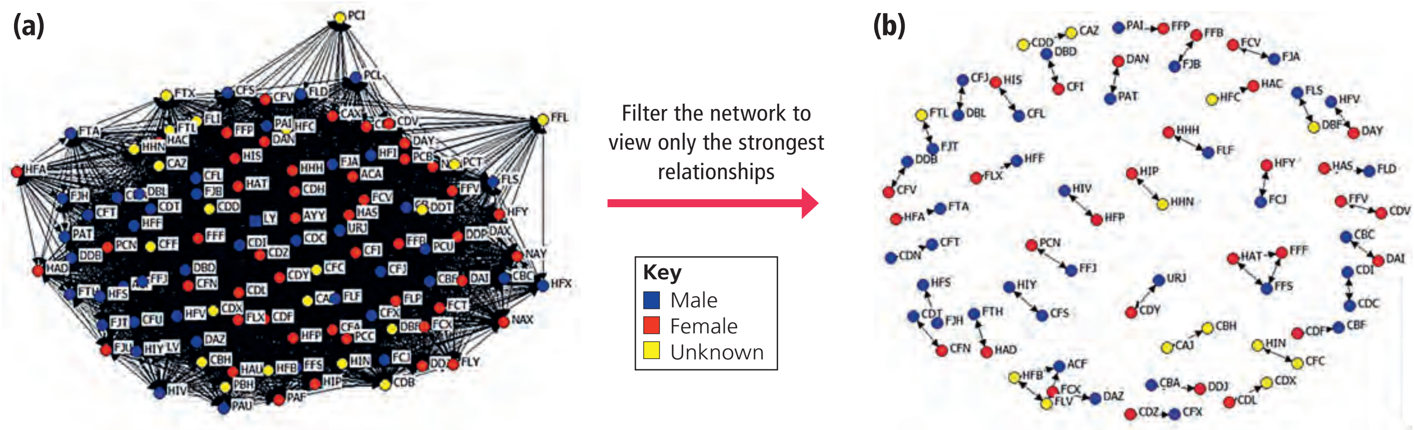


Figure 2 (a) In its raw form, the Chilean flamingo social network appears to be a dense jumble of nodes (coloured circles) and edges (black lines). (b) A filtered network shows only the strongest relationships within the flock. These are often different-sex and same-sex pairs, and polygynous (one male with multiple females) trios. The letters represent the three-letter Darvic codes

flock at some point during the 4-month period, which made the raw networks dense and difficult to interpret (see Figure 2).

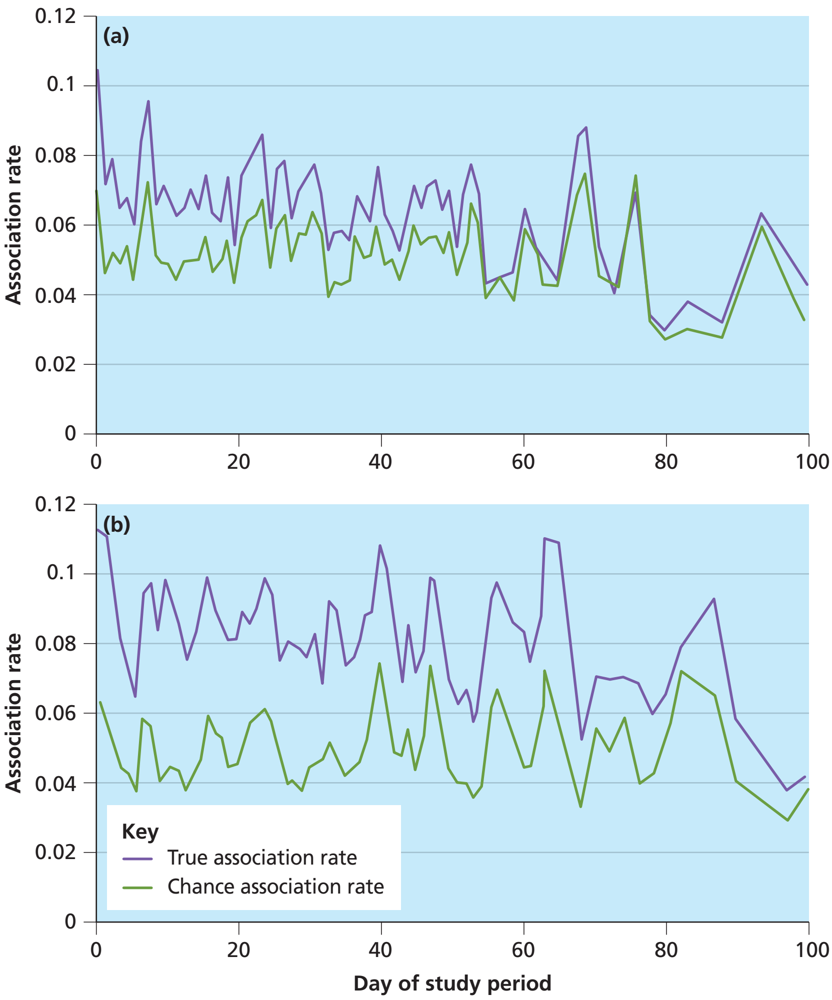


Figure 3 Comparison of the true (purple) association rates (the probability that two individuals that are associating on a particular day will associate again in the future) and the chance (green) associate rates (the expected association rate if the birds were associating at random) for the (a) Caribbean and (b) Chilean flamingos. In both cases, the true association rates were statistically higher than the chance associate rates, suggesting that the birds were *not* associating randomly

After filtering the networks to show only the strongest relationships, patterns started to emerge. The closest associates of the flamingos tended to be their breeding partners and a small network of non-breeding companions. To ensure that my results were scientifically sound I used statistical tests to compare the true association patterns with what would be expected if the birds were associating due to chance (see Figure 3).

The results were clear – the flamingos had preferred 'friends' with whom they chose to spend their time. Paul's wider work on other flamingo species returned similar results. There was still one big question for me to answer. How do flamingos choose their friends?

Birds of a feather flock together

Humans often choose friends based on personality, so is it possible that flamingos might do the same? If you spend time watching flamingos you might see some similarities between these flamboyant birds and children in a playground. There will be popular cliques, a couple of bullies and some quiet kids in the corner. Our observations suggested that similar birds were normally found together. We needed more evidence to support our suspicion that the birds selected their friends based on personality.

By watching the flamingos carefully, I connected specific behaviours to certain personality traits. For example, 'chrysanthemuming' – raising the back feathers to look bigger – indicates aggression.

THINGS TO DO

List ways in which anthropomorphism might impact a scientist's interpretation of an animal's behaviour.

Individuals that performed this behaviour frequently were defined as being more aggressive. Conversely, birds that were often spotted fleeing from conflict were labelled as more submissive. Following 260 hours of behavioural observation, I built a personality profile for each flamingo in both flocks.

I incorporated these personality profiles into my SNA and found another clear result. Just like humans, the flamingos were statistically more likely to associate with companions who were similar in personality to themselves. It is easy to see ourselves in this result, and so the risk of anthropomorphism is high. This makes the scientific method used to collect these data even more important. It ensures that we remain objective.

What we can (and cannot) conclude

This study strongly suggests that flamingos have specific friends, which they choose based on personality. However, when it comes to explaining why they behave in this way, we can only speculate. If the birds are likely to act in a similar way to each other, each may be able to guess how other birds will behave in certain situations. For example, if an aggressive flamingo is likely to protect its equally aggressive friend in a fight, there is a high chance that its friend will reciprocate next time. This may make cooperation easier, which might help the birds in obtaining valuable resources such as nest sites and food.

Crucially, we did not observe the flocks for long enough to relate our results to breeding success, and we got mixed results when we investigated how personality impacted fighting. Thus, these potential explanations remain speculative. As no one can ask animals why they do what they do, this limitation is true of many behavioural studies. Such uncertainty should be clearly communicated by researchers when they report their results.

Science in action

Research on other species of bird suggests that having preferred companions can lower stress levels and stabilise social groups. It is likely that this is true for flamingos too, and so our results have many practical applications.

Firstly, flamingos should be given the time and space to find their own friends. This means keeping them in large flocks (so they have plenty of choice) and allowing them to move freely.

Secondly, as translocating captive animals is common, when swapping flamingos, zoos should consider moving friendship groups together. This way the birds can keep their old friends in their new home.

© Paul Rose

Chrysanthemuming – raising the back feathers to look bigger – is an aggressive behaviour used by flamingos

Finally, our method can be adapted to identify particularly aggressive flamingos, which may need to be managed if they start to cause problems in the flock. Science must inform change. Although there will always be more work to do, actioning these suggestions will be a step towards accomplishing our ultimate goal – improving the welfare of captive flamingos.

RESOURCES

Follow WWT Slimbridge's flamingos via its 'Flamingo diary' blog:
https://tinyurl.com/flamingo-diary

Read the full study in Scientific Reports:
https://rdcu.be/c9Wb8

Fionnuala McCully is a PhD student at the University of Liverpool. She is an ornithologist, studying how personality impacts the social and parental care behaviour of birds.

Masting

Many perennial plants show huge variation in annual fruit production. Years with bumper crops are known as mast years. Ecologist Andrew Hacket-Pain explains how this happens, and outlines the environmental significance of masting

As the leaves begin to turn yellow and brown this autumn, look carefully at the oak trees in your local park or wood. Are the trees covered in acorns, or are the fruits hard to spot?

Oaks, along with other common trees including beech, spruce and fir, all show huge variation in annual flower and fruit production. In some years, the trees invest heavily in reproduction, and in other years they produce close to zero flowers and fruit. Remarkably, this variation in the production of fruit, such as acorns (see Figure 1), beech nuts and pine cones, is synchronised between individuals growing in the same population – if one oak is producing many acorns, the likelihood is that all the surrounding oaks are doing the same. This phenomenon of highly variable and synchronised plant reproduction is known as masting.

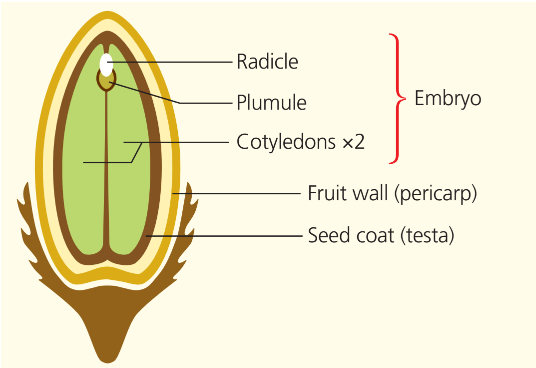


Figure 1 Section through an acorn (oak fruit – a nut)

How do plants do it?

While patterns of masting might look similar in different species (see Figure 2), the plants have quite different mechanisms that achieve this synchronised variation. Oaks, for example, produce a similar number of flowers each year, but the acorn crop reflects the proportion of flowers that are pollinated and then fertilised. Unfertilised flowers do not develop into acorns. This leads to variation in acorn crops between years.

Oaks are wind pollinated. Dry and warm conditions during the flowering period mean that pollen travels further and faster. This increases the efficiency of pollen transfer between flowers. So large acorn crops in the autumn tend to follow warm and dry springs.

In contrast, the varying crop size of beech nuts is mainly controlled by the number of flowers the tree produces in the spring. In a mast year, a beech tree will be covered in the small fluffy bauble-like male flowers, which hang downwards, and the less conspicuous, erect, female flowers. In a non-mast year it is hard to find any beech flowers. Annual flowering effort in the spring responds to an external temperature trigger, which in beech is temperature in the previous summer. As all individuals respond to the same trigger for mass flowering, beech trees synchronise within populations.

Masting is a major drain on plant reserves. Making all those fruits requires a major investment of organic carbon compounds (from photosynthesis) and mineral nutrients (from the soil). Consecutive mast years are rarely observed, and this is thought to be because plants take more than 1 year to recover their reserves after a mast year.

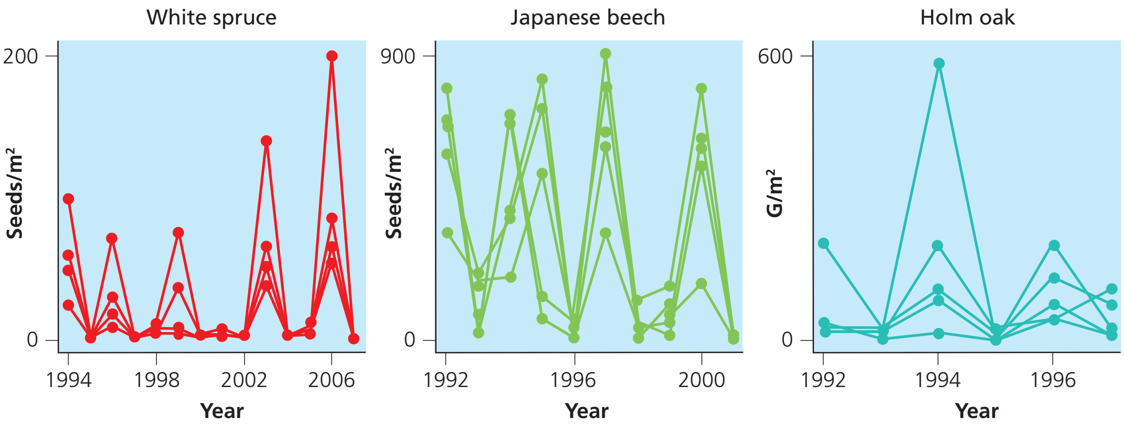


Figure 2 Population-level time series of reproductive effort in three masting plant species, illustrating the inter-annual variability and spatial synchrony that characterise masting. Each trace represents a different local population. In all cases the reported figures are means of numbers or grams of seeds collected in litter traps per square metre of ground surface

What is the benefit of masting?

We do not fully understand how trees regulate masting, but recent research has made a major step forward in understanding how it helps them. For masting to have evolved, it must have a selective benefit. So why do masting plants save up all their reproductive effort for occasional bumper years, at the cost of several, or even many, years of close-to-zero reproduction (see Box 1)?

Boom and bust

The most widely supported explanations are based on the economy of scale that emerges from the boom-and-bust cycle of masting. This is when concentrating output (fruit) into occasional mast years leads to lower long-run average costs (photosynthate and mineral resources).

Some plants have large, energy-packed fruit. This gives the germinating seed a rich energy source at the start of its life (think about how much energy is packed into an acorn, compared to a tiny birch or alder fruit – see Figure 3). However, large fruits are also attractive food sources for fruit-eating animals.

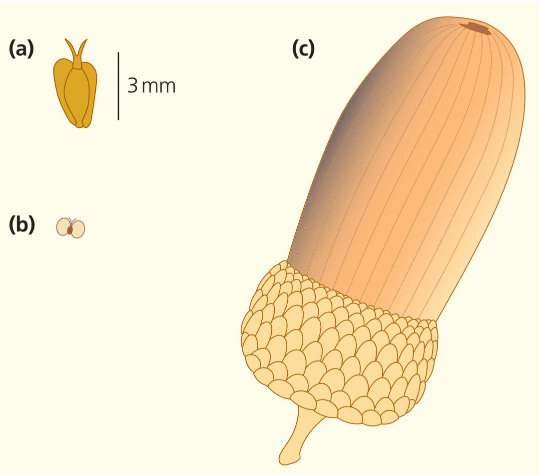


Figure 3 Drawings of fruits of three trees to scale, indicating large differences in energy stores. (a) Alder (*Alnus betulifolia*); (b) birch (*Betula alba*); (c) English oak (*Quercus robur*)

Years with very low fruit production starve populations of fruit-eating animals such as insects and forest-dwelling birds and mammals. This reduces the size of their populations. When a subsequent mast year arrives, the number of fruits produced overwhelms the capacity of the remaining animals to eat them all. Consequently, some fruits survive so that the seeds they contain germinate the next year.

This strategy of starving and satiating fruit predators – the predator satiation hypothesis – holds the key to successful reproduction. There is no point producing energy-packed fruits if only the animals get to benefit from them.

Box 1 Extreme masting

This article focuses on masting in trees, but masting is also found in other perennial plants. Masting in grasses can be particularly extreme, especially in bamboos. Many bamboos are plietesials, which means that they live for a number of years and then all the individuals growing in an area flower synchronously before dying. This is perhaps the ultimate example of masting.

For example, thanks to temple recorders, we know that in the years 919 and 1114, a Chinese bamboo, *Phyllostachys bambusoides*, flowered en masse. Sometime between 1716 and 1735, and again in 1844–1847, it flowered in Japan, long after being introduced there from China. In the late 1960s, transplanted stocks of this bamboo in England, Alabama and Russia, as well as the parental Japanese stock, flowered again. This bamboo thus has a masting cycle of about 120 years.

Chinese bamboo (*Phyllostachys bambusoides*)

A jackdaw breaks open the burr of a beech to extract the fruits

RESOURCES

To learn more about recent work on the environmental prediction hypothesis, see this blog article from the *Journal of Ecology*, 'Seed masting and fire disturbance synchronisation in white spruce': **https://tinyurl.com/y52cswwh**

A discussion about the environmental prediction hypothesis, and other masting-related topics, recently featured in *Science* magazine, 'Why are trees dropping so many nuts? Climate may drive erratic "masting"': **https://tinyurl.com/38dfm62b**

The New Zealand Department of Conservation (Te Papa Atawhai) has many resources on native wildlife management, including the ways in which masting cycles influence management decisions and the conservation of native species e.g. 'Predator control challenges with mega mast': **https://tinyurl.com/ysv4mh74**

and New Zealand's predator 'plague' cycle explained: **https://tinyurl.com/mh6rv8d7**

Mast years are not bad for all native New Zealand birds: 'Forest mast significantly boosts breeding of rare kākāriki/parakeet': **https://tinyurl.com/2p9herzm**

Pollination efficiency

The second explanation for the evolution of masting is the pollination efficiency hypothesis. Most plants are out-crossing. This means they cannot self-fertilise – successful pollination only occurs if they transfer their pollen to the flower of another individual. Female flowers that are not fertilised represent a waste of energy. Concentrating flower production into isolated mast years ensures effective pollination. There are so many male flowers in a mast year that the air becomes heavy with pollen, increasing the proportion of female flowers that are fertilised. This increases the overall efficiency of reproduction, providing a benefit for plants that have evolved masting.

Young oak leaves and flowers in spring

Environmental prediction

These two explanations for masting are recognised as having the largest body of supporting evidence. Masting increases overall reproductive efficiency (minimising the 'cost of reproduction') by maximising the number of female flowers that are successfully pollinated and minimising the proportion of fruits that are lost to predators. Recent work has also revived a third theory that argues that masting can be beneficial if it enables plants to time bumper fruit crops to take advantage of favourable conditions for seed germination and establishment. This is called the environmental prediction hypothesis.

This hypothesis proposes that plants benefit if they time their large fruit crops to take advantage of favourable conditions for seed germination and seedling establishment. Plants cannot forecast the future but in several geographical regions, plants track oscillating modes of climate variability. For example, in tropical southeast Asia, plants can take advantage of the oscillating nature of the El Niño–Southern Oscillation climate pattern to prepare for the arrival of favourable conditions. The drought conditions associated with El Niño trigger mass flowering efforts. This means that by the time the fruits have ripened and been dispersed, dry conditions have (usually) given over to La Niña-induced rains, which favour germination and seedling establishment.

Why is masting important?

The large pulse of energy-rich food associated with mast years has major impacts on the dynamic of forest ecosystems, and the effects of a mast year cascade through food webs. In New Zealand, for example, the consequences of masting cycles in native forests can be catastrophic (see Figure 4). Carefully coordinated management of non-native mammal pests is required, in order to conserve the iconic native wildlife of New Zealand.

In mast years, small mammals such as (introduced) mice and rats gorge on the abundant tree fruits, and their populations explode. This in turn increases the population of (introduced) stoats, which feed on the mice and rats. Eventually the supply of fruit runs out, and the large populations of mice, rats and stoats turn to other food sources, including the eggs of native birds.

As they evolved in the absence of placental mammals, the native birds are ill-prepared for this intense predation by non-native mammals. The 'plagues' of mammals have devastating effects on the reproductive success of the native birds, many of which are endangered.

But other species benefit. For example, the kākāriki, New Zealand's rarest mainland bird, benefits when native species are masting. The abundance of food allows these parakeets to reproduce during the New Zealand winter, thus boosting their numbers and helping to combat the effects of non-native predators.

What about climate change?

Both masting and natural disturbances can be triggered by specific climatic conditions. For example, droughts increase vegetation flammability, while those same warm dry summers encourage the development of reproductive tissues in the following year. So, climate patterns conducive to severe large-scale natural disturbances, such as fire, also trigger masting in some species.

For example, in an area prone to burning by fire, cone production by white spruce (*Picea glauca*) in boreal forests of western North America was analysed (see Figure 5). Drought events increase the number and size of wildfires. This increases the total area of forest burned, and masting occurred significantly more frequently after years with lower-than-average rainfall. Consequently, white spruce trees growing in unburnt patches of forests produce large numbers of cones in the year following widespread fires, creating a crop of seeds capable of regenerating the lost trees in the years following the fire.

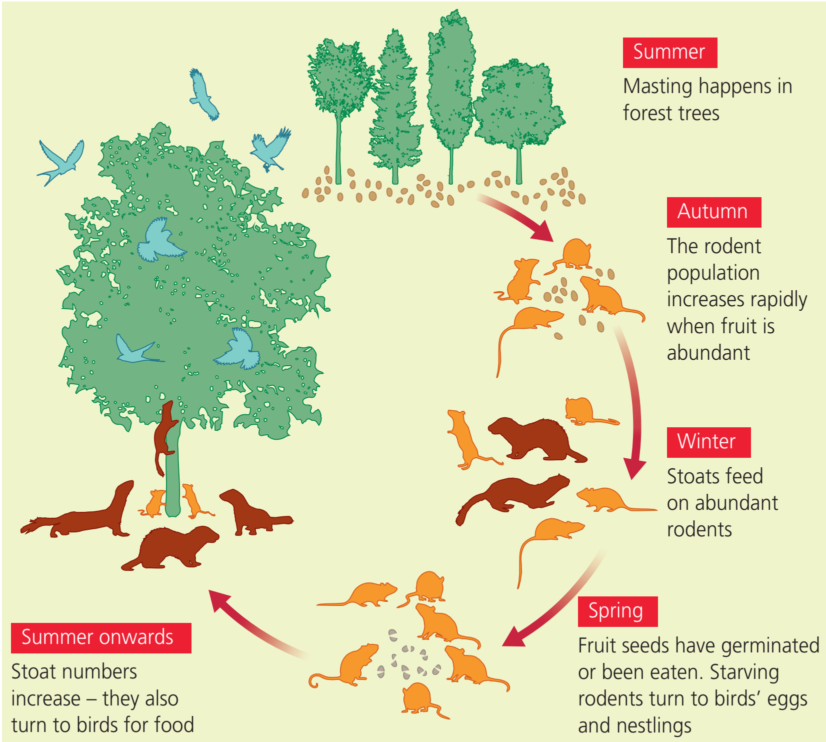


Figure 4 The predator/'plague' cycle of New Zealand forests

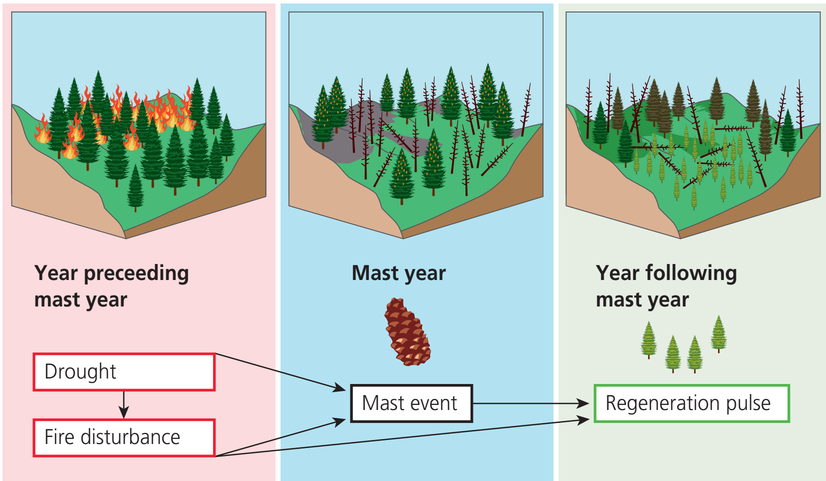


Figure 5 How climatic changes trigger masting in white spruce

Crucially, fire disturbances favour seed germination, seedling emergence and establishment by exposing mineral-rich soil, increasing light at the forest floor, and reducing competition by understorey vegetation. Consequently, seeds that are dispersed after a fire have a higher chance of successfully establishing. So the ability to synchronise large crops with large-scale disturbances is a key asset for the persistence of white spruce in fire-prone landscapes, providing it with higher than expected climate change adaption capacity.

Dr Andrew Hacket-Pain is a senior lecturer in biogeography and ecology at the University of Liverpool. His research focuses on understanding and predicting the impact of global environmental change on forests.

SPOTLIGHT

Hedgehogs in crisis

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

Box 1 What do hedgehogs eat?

An average sized hedgehog expends 90–150 kilocalories of energy per day and spends around 80% of its active time foraging for food. Hedgehogs are omnivores, meaning that they eat animal-based and plant-based foods. They mostly eat beetles, earthworms, slugs, earwigs, caterpillars and millipedes but also sometimes take amphibians, chicks, eggs and fallen fruit. Adult hedgehogs should ideally have a mass of at least 600 g in order to survive hibernation as they rely on having sufficient fat reserves (see Box 2).

Box 2 Hibernation

In Britain, hedgehogs, dormice and bats are the only mammals that are true hibernators. They don't simply go to sleep. Hibernation is a complicated energy-saving strategy involving physiological changes. Temperature, breathing and heart rate all reduce. This lowers energy use. Hedgehog bodies cool from 35°C to 10°C or less, and heart rate decreases from around 190–280 to under 14 beats per minute during hibernation. Hedgehogs have also been found to stop breathing for up to 90 minutes during hibernation – a phenomenon called apnoea. These apnoeic episodes help to conserve water and energy.

About 30% of an average-sized adult hedgehog with a mass of 600 g comprises fat. Average hedgehog daily energy expenditure when active falls by over 200 times during hibernation, helping to conserve these precious fat reserves. Despite this, for each day they spend in hibernation, hedgehogs lose 0.2% of their original body weight. Hedgehogs therefore die if they are underweight when they enter hibernation.

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

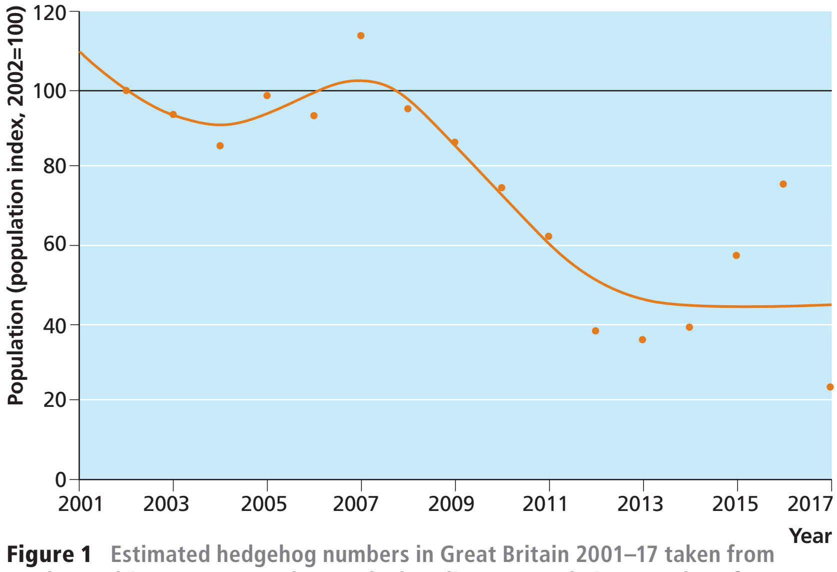


Figure 1 Estimated hedgehog numbers in Great Britain 2001–17 taken from road casualties. 2002 was taken as the baseline year and given a value of 100. The circles are annual estimates, the line shows a smoothed trend, which indicates a decline of >50%

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**. 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


European hedgehog hoglets

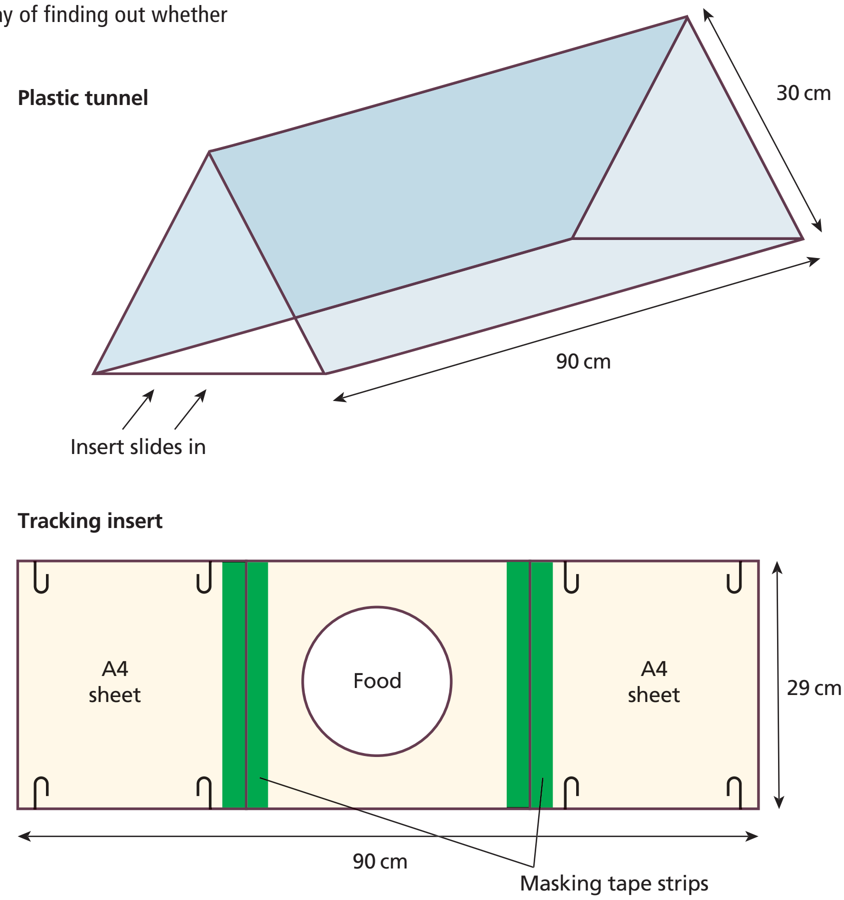
Box 3 Make a tracking tunnel

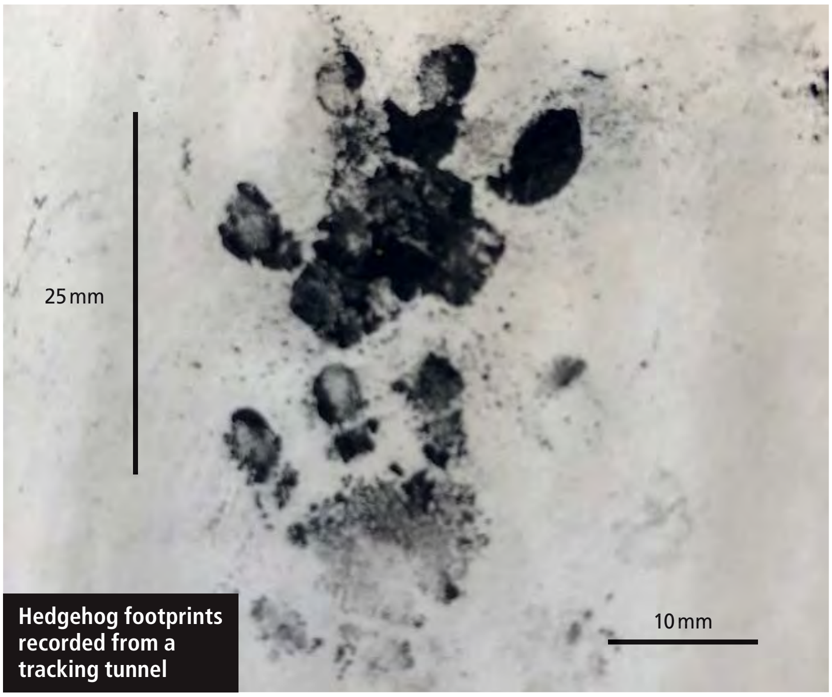
Tracking tunnels are a straightforward and effective way of finding out whether hedgehogs are using a habitat. You will need:

- 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**)





Hedgehog footprints recorded from a tracking tunnel

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.

Hedgehogs can get trapped in garden fencing

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**

Johnson, H. and Thomas, E. (2015) 'Guidance for detecting hedgehogs using footprint tracking tunnels': **https://tinyurl.com/yah558e5**

'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.

Horseshoe crabs

Are they crabs?

These charismatic creatures are keystone species. They also have evolutionary, historical, commercial and biomedical importance. Biodiversity enthusiast Liz Sheffield shines a spotlight on them


Horseshoe crab fossil from the Jurassic period

There is a saying: 'A rose by any other name would smell as sweet'. Right? Perhaps we will leave the naming dilemma for later and examine why we are spotlighting an animal few readers will ever encounter.

It is mostly because it has something for almost anyone interested in biology. Its evolutionary history can be traced back almost half a billion years. In 2020, researchers described a fossil found in what had been a seashore environment 480 million years ago and named it *Lunataspis aurora*, meaning literally 'crescent moon shield of the dawn'. The resemblance to modern-day horseshoe crabs was unmistakable, and fossils from the **Jurassic period** are indistinguishable from animals that have hoovered along seashores ever since (see Figure 1).

Horseshoe crab adaptations

Hoovering is not a scientific term of course, but it neatly describes how horseshoe crabs feed. These animals are bottom-dwelling scavengers. They scuttle around on five pairs of legs, using their legs and claw-like feeding appendages (chelicerae – see Figure 2) to shovel or pick up prey and detritus. They move the food to a bristly area at the base of the front legs where it is crushed (they have no jaws) and sucked into the mouth. They can grow very large – a Japanese specimen of *Tachypleus tridentatus* recorded at 79.5 cm long and weighing 5 kg currently holds the record. Nonetheless, the pincers of even the biggest specimens are relatively small and weak, and completely harmless to anything larger than a worm.

Figure 1 Current distribution of the four living species of horseshoe crab

But what about that vicious-looking rearmost spike (telson)? This is not a weapon but rather the means by which horseshoe crabs can try to flip themselves if they are deposited on the shore the wrong way up by a wave. (Fans of *Robot Wars* will be familiar with the principle.)

Horseshoe crabs are covered by an exoskeleton called a carapace. This contains structural proteins stiffened with chitin – a tough, resistant nitrogenous polysaccharide that is flexible, lightweight and resistant to decay. The front section is joined to the abdomen by a flexible joint. The abdomen has a series of plates, which both protect the gills and aid a flip-swimming motion in open water. The crabs have two compound eyes on top of their carapace (good at detecting movement and mainly used to locate a mate) and two simple eyes near the front. The simple eyes are used for light detection and are sensitive to ultraviolet light. All these features characterise animals that are supremely well adapted to living in turbid waters on shorelines.

Keystone species

The long-running success of horseshoe crabs has made them critically important to many of the ecosystems they inhabit. In Delaware Bay (USA), for example, up to 1.5 million shore birds visit during the last 2 weeks in May, for the annual horseshoe crab migration onto shore.

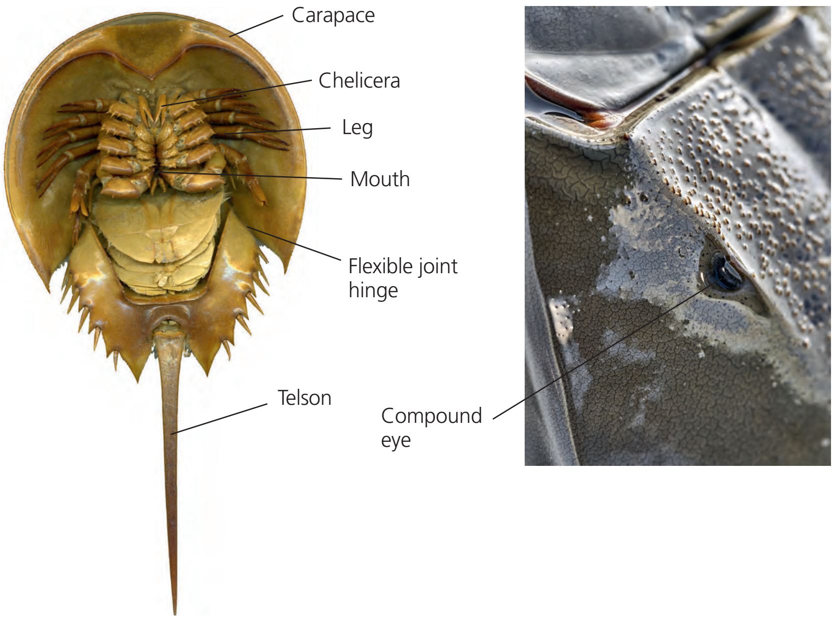


Figure 2 Structure of a horseshoe crab (*Limulus polyphemus*)

The crabs come ashore to mate. Males cluster at the sea's edge on the night of the highest tide. When a female arrives, a male grabs her with boxing-glove-shaped claws at the end of his first pair of legs. He hangs on while the female pulls herself up the beach to the high tide line. The female digs a hole and deposits about 100000 pearly green, tiny eggs, which the male (externally) fertilises as he is pulled over the nest.

Unpaired males gather around mating pairs, also releasing sperm during egg laying. Genetic analysis of the progeny shows that two unpaired males are as successful as one paired, in terms of paternity. The eggs are warmed by the sun and protected from waves until the larvae hatch and are returned to the sea by the next high tide. In the meantime, however, there is a bonanza for the shore birds and, in some parts of the world, for humans, who eat the eggs in salads.

Horseshoe crabs themselves are eaten in some parts of Asia and can be purchased in **wet markets**. They are also harvested commercially as bait for the American eel, conch and whelk fisheries. Restrictions have been placed on bait harvests in the Delaware Bay area of 500000 male-only horseshoe crabs since 2012. The limits have been imposed because over-harvesting has seriously depleted numbers.

In the early 1900s horseshoe crabs were so abundant they were used as fertiliser and livestock feed. Chitin from their exoskeletons has been used in contact lenses, skin creams and hairsprays. These animals are currently still of huge importance in the biomedical industry.

Female horseshoe crab (furthest right) pulling herself out of the water at high tide. One male is attached to her and will fertilise her eggs when she lays them in the sand but the male lurking beside the pair can also expect to father some of the progeny

Box 1 The downsides of blood 'donation'

During the breeding season every year in the USA, fishers collect more than 600000 horseshoe crabs. They are transported to laboratories where up to 30% of their blood is removed, before they are returned to the sea. Researchers who mimicked this process found that animals that survived being bled behaved significantly differently from control animals for several weeks after the procedure. They moved less (see Figure 1.1) and with different patterns and rhythms, suggesting that they were disorientated.

The research also showed that the blood of the bled animals had not been restored to its original constitution many weeks after the procedure. Figure 1.2 shows haemocyanin levels of blood of animals kept both in laboratory and outdoor tanks after bleeding.

This indicates that the blood of animals returned to the wild after bleeding has a reduced capacity to carry oxygen, in addition to the deleterious effects of removing many of the amoebocytes that normally protect the animals from infection. These findings are in line with data from human blood donors, which show that although white cells are replaced in a matter of days, it takes 6–12 weeks for haemoglobin levels to return to normal. Therefore, human donors are advised to avoid strenuous exercise after donating blood, but horseshoe crabs returned to the wild don't have the option of taking things easy.

Scientist bleeding horseshoe crabs

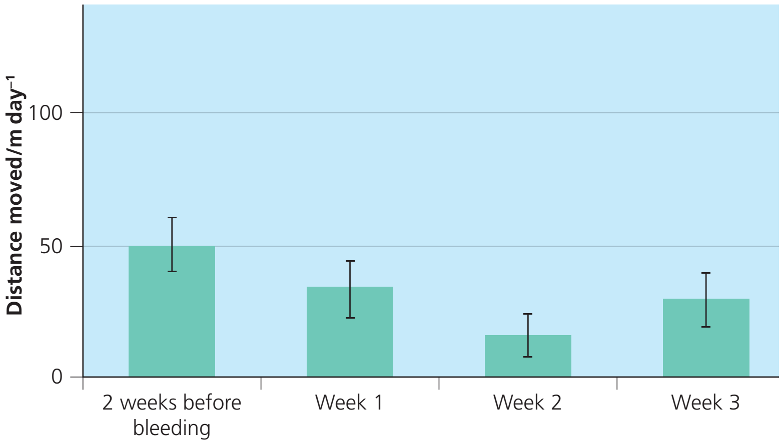


Figure 1.1 Effect of bleeding on distance moved (mean ±SEM) in horseshoe crabs

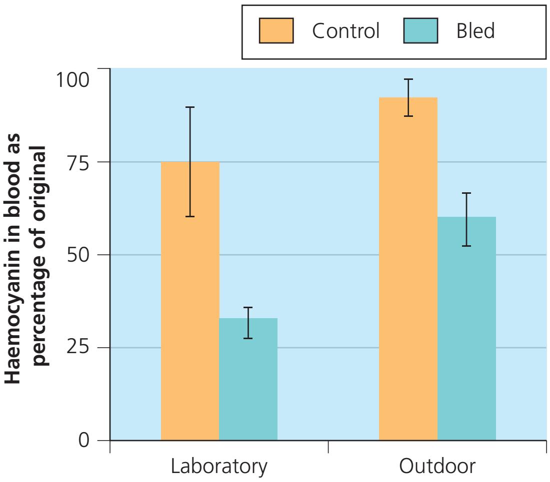


Figure 1.2 Percentage of original haemocyanin concentration remaining 6 weeks post-bleeding

Blue bloods

In the 1950s, an agent was discovered in horseshoe crab blood that clots the blood in response to bacterial **endotoxins**. These bacterial products can sometimes prove deadly in other animals as they hyperactivate their immune systems. This can result in fever, which can escalate to organ failure or septic shock.

There are over a billion bacteria per gram of sand or mud near the shore. It is therefore not surprising that horseshoe crabs have a system that protects wounds from bacteria. The oxygen-carrying molecule in their blood is haemocyanin – based on copper (not iron, as in haemoglobin) so turns blue as soon as it is oxidised. The blood includes amoebocytes that detect bacterial toxins. These cells change shape and engulf bacteria, or adhere to sides of wounds, forming a clot. This phenomenon is now part of the pharmaceutical *Limulus* Amoebocyte Lysate (LAL) assay. This tests for the presence of bacterial toxins and can be used both to reveal and quantify them.

Up to 300 cm^3 blood is taken from (live) horseshoe crabs and centrifuged to pellet the amoebocytes, which are then homogenised to obtain clotting factors. The LAL reagent is then incubated with the test product, e.g. part of a batch of pharmaceuticals. The reaction is sensitive, fast, cheap and an 'animal-free' method to detect contamination. (Most testing prior to the discovery of LAL involved exposure of rabbits to suspected toxins, then waiting to see how their immune system reacted.) More than half a million crabs are bled each season, before being returned to the ocean. Resultant mortality is said to be 'only' 10–45%, but concerns have prompted research that revealed death is not the only downside for the animals (see Box 1).

Fortunately for the crabs, this practice may be dying out. Early in the 2000s, researchers discovered that a molecule in LAL, called factor C, was responsible for its clotting action. They genetically modified insects to produce factor C. This recombinant factor C (rFC) has now been approved for sale as a substitute for horseshoe crab blood.

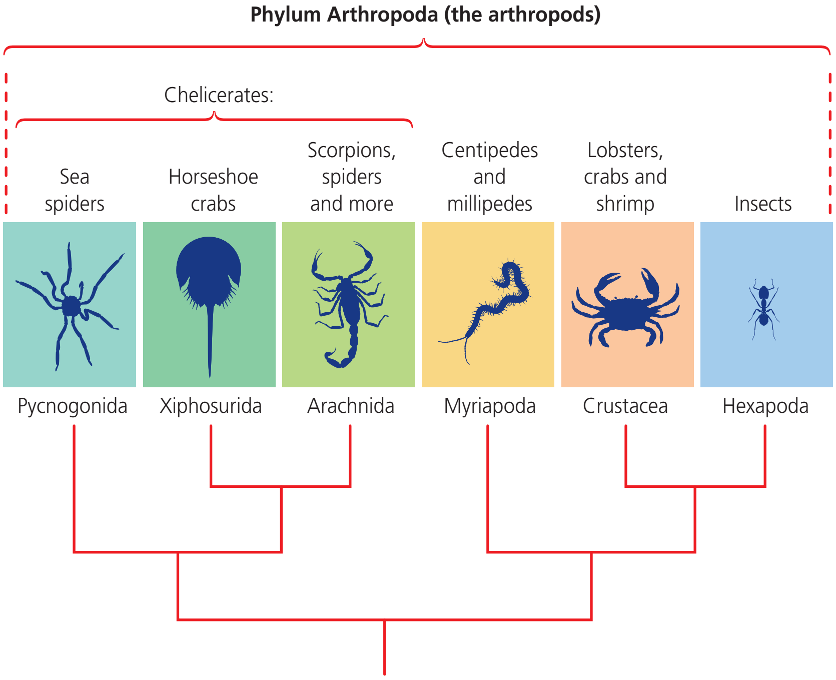


Figure 3 Conventional family tree of arthropods

What's in a name?

To answer this we first need to consider the significance of common names. 'Crab' is not a scientific term, but one that can be defined as 'sea creature with five pairs of legs and a round, flat body covered by a shell, or its flesh eaten as food' (Cambridge dictionary). So, leaving aside the 'horseshoe' part (perhaps 'horsefoot' would be a better description), there is no huge problem with the crab part of the name. However, scientists are usually keen to restrict the term crab to members of the class Crustacea. Two of the defining features of this class are 'crusty' exoskeletons strengthened with calcium carbonate, and the possession of jaw bones (mandibles). Horseshoe crabs have a flexible exoskeleton strengthened with chitin, and lack mandibles, so they certainly aren't crustaceans.

Until recently, horseshoe crabs have been classified based on their observable characteristics into a group of chelicerates distinct from both crustaceans and arachnids. The latter group includes the spiders, all of which have eight legs and are terrestrial. But, while arachnids and horseshoe crabs may have diverged from a common ancestor chelicerate, they haven't diverged very far. Recent genome sequencing of living spiders and horseshoe crabs suggests that they should both be in the same group. As with all matters of taxonomy, the family tree (Figure 3) is a work in progress, but horseshoe crabs certainly are arthropods – the largest and most successful phylum on Earth.

TERMS EXPLAINED

Endotoxin A toxin inside a cell.

Jurassic period 199.6 million to 145.5 million years ago.

Wet market A market with open air stalls selling fresh meat, fish and perishable produce.

RESOURCES

Watch horseshoe crabs swimming: **www.youtube.com/watch?v=DPpib7X7i-8**

Drake, N. (2022), 'Bizarre horseshoe crabs are actually spider relatives', *National Geographic*: **https://tinyurl.com/47djayuk**

Davis, M. (2022), 'Horseshoe crabs are drained for their blue blood. That practice will soon be over', Freethink: **https://tinyurl.com/3sdzd7t4**

Read, Z. (2022), 'Controversial proposal would lift limits on horseshoe crab harvesting in the Delaware Bay', WHYY: **https://tinyurl.com/2hab3kjm**

Why horseshoe crab blood is so expensive: **www.youtube.com/watch?v=LgQZWSlLBnA**

Professor Liz Sheffield is associate pro-vice chancellor (education) in the Faculty of Science & Engineering at the University of Liverpool and chair of editors of Biological Sciences Review.

It's a hard life on the rocky shore

How organisms cope with a constantly changing environment

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

Jack Thomson

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

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.

Key words

Behaviour
Ecology
Habitat
Species
Community

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.

BiologicalSciencesReview*Extras*

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

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.

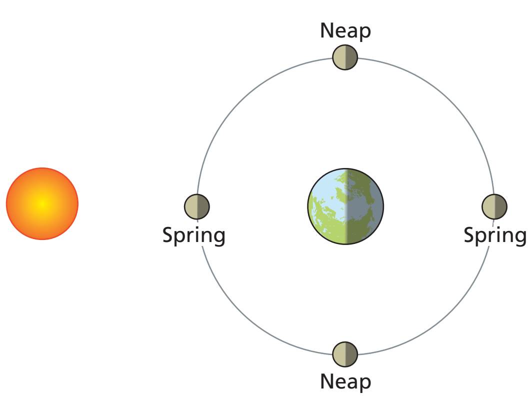


Figure 1 Relative positions of the Sun, Moon and Earth during the lunar cycle, and how these influence the tides. Spring tides have the widest range between high and low tide, neap tides the smallest

Gastropods, such as whelks and these periwinkles have a hard outer shell that protects them from predators and a harsh environment. Many marine snails also have a hard plate, or operculum, which covers the shell's opening, and reduces desiccation

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

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

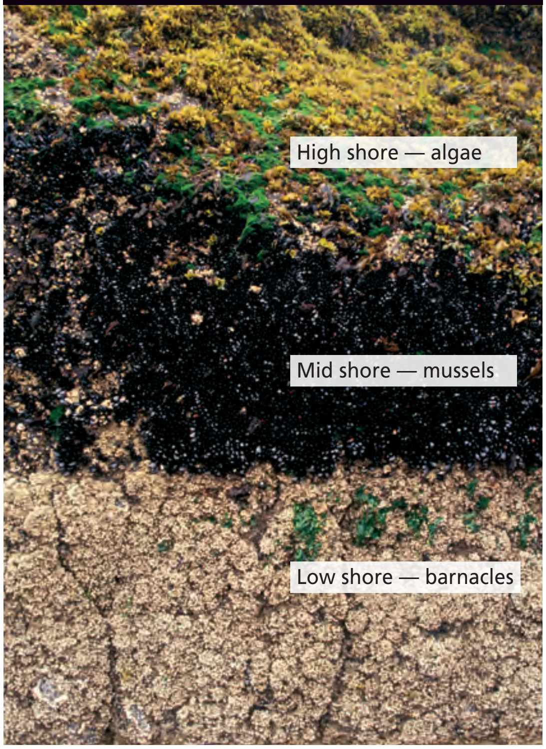
The biological interactions between and within species in a community involve a complex interplay between predation, grazing, competition and its inverse, facilitation (see Box 1). On rocky shores, potential competitors may be kept in check by predators, but competition is a major force driving community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

A contest between anemones. The anemone on the right has its fighting tentacles inflated and strikes down on its opponent

Three distinct zones on an exposed rocky shore, consisting of algae higher up but giving way to mussels in the mid shore and barnacles in the low shore



Shore crabs can be extremely aggressive and take a fighting stance when faced with a threat

the inclination to obtain a potential mate that male crabs will grab and hold on to any inanimate object coated with these pheromones.

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.

Further reading

More information on rocky shores and the challenges organisms face there: **www.marbef.org/wiki/Rocky_shore_habitat**

Information on sandy shores — also a tidal habitat but with very different ecology: **www.marbef.org/wiki/Sandy_shores**

Lots of information about the wonderful range of organisms found on rocky shores: **https://tinyurl.com/y77zq6tz**

Find out more about tides: **www.ntslf.org/about-tides/tides-faq**

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.

BiologicalSciencesReview*Extras*

Go online for 'Sea anemones stinging, fighting, swimming, reproducing and contributing to human health'
www.hoddereducation.co.uk/bioreviewextras

Dr Jack Thomson is a lecturer in marine and behavioural ecology at the University of Liverpool. He studies how aquatic animals respond to environmental challenges, including the influence of 'personality' on behaviour.

Key points

- The rocky shore is a dynamic environment with regular submersion by seawater and exposure to the air.
- Shore organisms face a range of challenges from other organisms and from their changing environment.
- How they cope with these challenges defines their position on the shore.
- Motile and sessile organisms use different strategies to cope with the stresses of life on the shore.

Banana blight

Why bananas could disappear from our fruit bowls

Young bananas growing on an uninfected plant

Best loved fruit

Bananas are the number one fruit crop in the world. They are the fourth largest crop overall, after wheat, rice and corn. They share a problem with all these cultivated plants, however, and that is susceptibility to disease. This is a particularly severe problem for plants propagated vegetatively, such as bananas. All bananas are genetically very similar, so a pathogen that affects one of them will be able to damage all of them — something that would not be the case if bananas were genetically variable. The black Sigatoka fungus causes the worst problems. Its name comes from the Sigatoka Valley in Fiji where it was first identified in 1912. Over the next 40 years, the disease spread to all banana-producing countries. Black Sigatoka appeared in Central America in 1934 and in 2 years had destroyed more than 8900 hectares of banana in Honduras and Suriname. Without intervention, this fungus can devastate whole plantations, causing up to 100% fruit loss.

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Black Sigatoka life cycle

Figure 1 shows the asexual life cycle of the fungus. If a spore is splashed on to the leaf of a neighbouring plant, within 2–3 hours it produces a germ tube, invisible to the naked eye. This grows on the surface of the leaf until it encounters a stoma, whereupon it grows inside and starts colonising the leaf. For up to 40 days there is no sign that anything is amiss, then gradually lesions start to appear (see Figure 2). By this time, spore-producing tissues have emerged from stomata and started to release yet more spores (see Figure 3). It is the sugars produced by the leaves that fuel the development of fruits, and so plants infected with the fungus produce fruit of such poor quality that they cannot be sold.

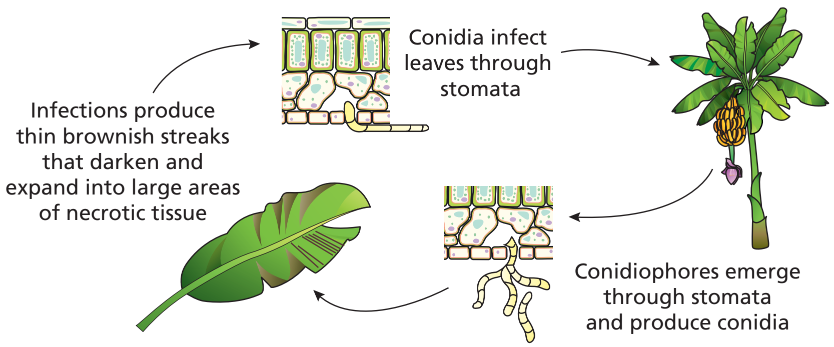

Figure 1 Life cycle of black Sigatoka fungus. Conidia are multicellular spores which are transmitted to neighbouring plants via rain splash

Figure 2 Banana leaf infected with black Sigatoka fungus

Figure 3 Coloured scanning electron micrograph of fungal conidiophores — spore-producing tissues (grey) emerging from the underside of a leaf ×265

What can be done?

The only treatments that can thwart the fungus are fungicides, and in many parts of the world these are sprayed from planes over huge swathes of banana plantations — in some regions up to 50 times every year. In addition to the obvious environmental impact, there are several problems with this approach. The greatest drawback is the selective pressure the fungicides exert on the fungus, favouring the emergence of resistant strains. Many farmers in developing countries cannot afford fungicides. Many consumers are keen to obtain organic produce — uncontaminated by agrochemicals. So plant researchers are working hard to develop varieties of banana that are resistant to the fungus. This might be relatively straightforward if it were possible to cross-breed different varieties or strains and select for resistant progeny. This is not feasible with edible bananas, however, as they do not produce viable seeds.

The resistance movement

There are two main approaches being used to generate Sigatoka-resistant bananas. One uses non-edible bananas which are resistant to the fungus. In 2012, researchers in Ecuador isolated the genes responsible for conferring resistance. Since then, laboratories around the world have been working with genetic transformation techniques to engineer these genes into edible bananas. The second approach is to bombard plantlets of edible banana with gamma rays and X-rays, which cause DNA mutations, some of which by chance will confer resistance. There are currently three mutants which, in laboratory conditions, show resistance to the fungus. If these plants prove resistant to the fungus in plantation conditions, and generate fruit that matches that of the conventional crop, plant geneticists will have saved our best loved fruit for future generations to enjoy.

Further reading

To see how edible bananas are propagated without using seeds see:
www.youtube.com/watch?v=sLoZbDnAPIk

Is the means of combating Sigatoka described in this video 'natural'?
www.youtube.com/watch?v=lb8_f_VwPhc

Liz Sheffield, University of Liverpool and
Kevin O'Dell, University of Glasgow.

Cultivating clones

Why do crop growers want asexual reproduction?

Commercial crop producers aim for desirable and lucrative produce. One attribute of many plants, shared by very few animals, particularly helps the achievement of this aim — asexual reproduction. This is a process through which one organism produces another, without the involvement of gametes or mating.

Asexual reproduction means that new individuals are generated from new material via mitosis, which in turn means that they are genetically identical to (clones of) the original organism. If you have a good crop — one that has all the characteristics you or your customers want — the last thing you want to happen is for random associations of alleles to end up in the next batch of produce. But that is exactly what happens in sexual reproduction — the process that precedes the production of most seeds — where offspring inherit random assortments of alleles from each parent because of the meiosis that precedes gamete formation. This is why commercial crop producers make the most of asexual reproducers such as strawberries and potatoes.

Strawberries

Strawberries form more than half the world's soft fruit market, which is worth over £1.2 billion every year. Figure 1 shows how they propagate vegetatively — horizontal stems called stolons generate new plants via mitosis at their extremities. All the crop producer has to do is anchor the stolons to the soil (or potting compost), and the stolons do the rest.

Figure 1

Potatoes

Potatoes are grown in more than 100 countries and are estimated to be worth more than £4.8 billion per year. Figure 2 summarises asexual reproduction in this versatile vegetable. The starchy tubers are fattened during summer months from the photosynthates produced by the above-ground stems and leaves, which die down in winter. The tubers produce new plants each spring, colonising the area with clones of the original individual.

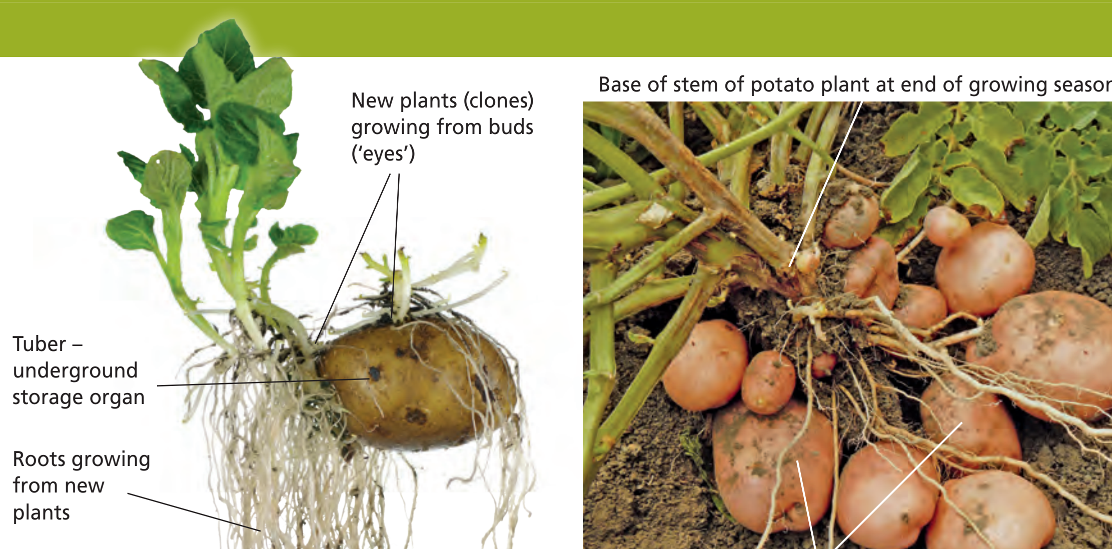

Figure 2

Rice

The difference with rice

Rice is the most valuable agricultural crop in the world, and the basis of the diet of more than half the world's human population. But until recently, this important cereal could not be reproduced asexually. For almost a century, rice crops have been grown from hybrid seeds created by growers crossing two varieties. These hybrids have superior qualities (e.g. yield, pest resistance) but their seeds do not produce plants with the same qualities, because of the random combinations of alleles that come together during sexual reproduction. Growers have to purchase hybrid seed from suppliers every year, which is prohibitively expensive for many small-scale farmers in the developing world.

Something new for rice farmers

Researchers in the USA have now made rice plants that grow as clones from seed. First, they used gene editing to remove the genes responsible for driving meiosis. This generates egg cells — female gametes — formed by mitosis. Each therefore has the same, diploid, number of chromosomes as their parent plant. The researchers had discovered that the male rice gamete normally triggers expression of a gene that causes embryo formation. They caused egg cells to express this gene, leading to formation of embryos, and in turn viable seeds. This form of 'virgin birth' happens naturally in several hundred (non-crop) plants, and some animals (including stick insects, snakes and sharks). Success with introducing it to rice, and potentially other crop plants, seems certain to improve our ability to feed the world's growing human population.

Liz Sheffield, University of Liverpool

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Further reading and viewing

University of California Davis, 'Rice plants that reproduce as clones from seed': **https://tinyurl.com/yxu2cbo2** (includes a movie that explains the research).

BBC Earth, 'Many animals can give birth without mating': **https://tinyurl.com/y6o64voz**

Biological Sciences update
DECEMBER 2018
www.hoddereducation.co.uk/biologicalsciencesreview

Food for thought

Palm oil is found in more than 50% of the products in most supermarkets. **Liz Sheffield** examines the effects its production has on forests and their inhabitants

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,

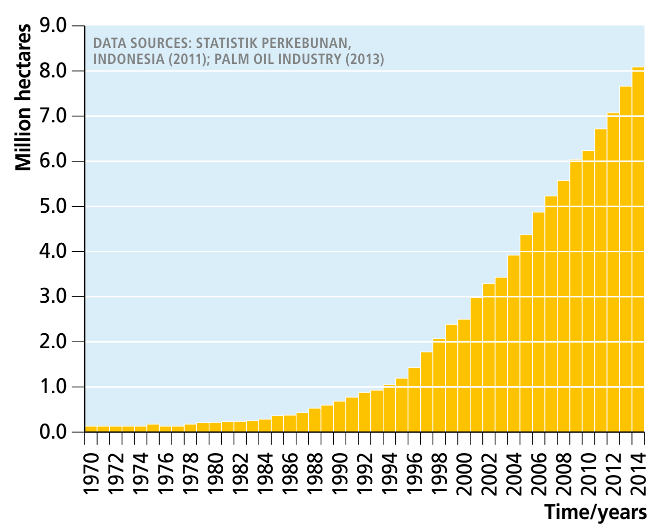

Figure 1 Indonesia's historical oil palm area

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

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DECEMBER 2018
www.hoddereducation.co.uk/biologicalsciencesreview

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).

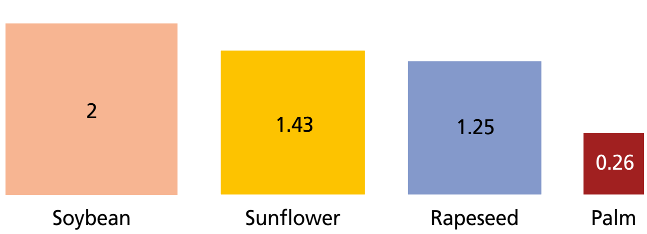

Figure 2 Area of land (hectares) required to produce 1 tonne of different oils

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!

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**) 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.

Further reading

'Despite government claims, orangutan populations have not increased', *ScienceDaily* News, 5 November 2018: **https://tinyurl.com/ybf3ym6y**

'"Sustainable palm oil" may not be so sustainable after all', ABC News Australia: **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**

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Microgreens on Mars?

The landscape in this artist's impression may be a little fanciful but the veggie cultivator is very real. Veggie 01 was first used on the International Space Station (ISS) in 2014. Veggie was designed to be a low mass, low crew time-requiring, low power-consuming, simple, expandable, food crop production system. The first version of Veggie proved extremely successful, with testing confirming that the products were safe, nutrient-rich and tasty. Astronauts were soon munching on lettuces germinated and cultivated in the microgravity of space.

The basis of the cultivator was plant 'pillows' — small packages of material topped with surface-sterilised seeds and transported into space. These 'pillows' were then hydrated and illuminated with LED lights to trigger germination and encourage growth. Success with new Veggie designs and several other crop plants quickly followed. ISS astronauts now routinely harvest fresh, vitamin-packed vegetables to supplement their diets.

Another development that attracted huge attention, from both the media and psychologists interested in mental wellbeing, was the astronauts' celebration of their successful production of the brightly coloured and perfectly formed flowers of *Zinnia*.

The most recent ISS experiments have used Veggie 05, incorporating a passive orbital nutrient delivery system (PONDS) — a hydroponic system (see pp. 26–29), which has proved successful with larger and high water-requiring plants, including tomatoes. This research has been coupled with simulations of Mars landings in the Dhofar desert in Oman, where researchers used hydroponic systems to produce micro-vegetables with nutritional values of 4–40 times that of adult plants. As the researchers observed: 'The concept of a Martian veggie plot goes beyond space research, as it can be used to test "circular economy" applied to primary production in conditions that reduce the need for energy, water and fertilizers.'

Professor Liz Sheffield, University of Liverpool

A *Zinnia* plant blooming on board the International Space Station

Further reading

'Martian vegetable plots as a solution to waste': **http://tinyurl.com/y529jbwb**

'This NASA Experiment Shows Promise for Farm-Fresh Foods in Space': **http://tinyurl.com/y5zz2k55**

'How NASA is learning to grow plants in space and on other worlds': **http://tinyurl.com/ydhb3xq5**

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Biological Sciences
update
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Insectinction

Insects are in catastrophic decline across the world. **Liz Sheffield** explains the causes, and some current efforts to combat them

The German government recently warned against the use of leaf blowers over concerns for insects and the environment. The German Ministry for the Environment issued guidance which suggested that leaf blowers should not be used except where they are 'indispensable'. The Ministry said that leaf blowers posed a fatal threat to insects. The guidance follows studies showing that insect numbers have plummeted in Germany and across the world (see Figure 1). A study conducted in 2017 found that flying insects had declined by more than 75% over almost 30 years at 60 sites in Germany.

An action plan to protect insects, estimated at a cost of €100 million, was announced by the German

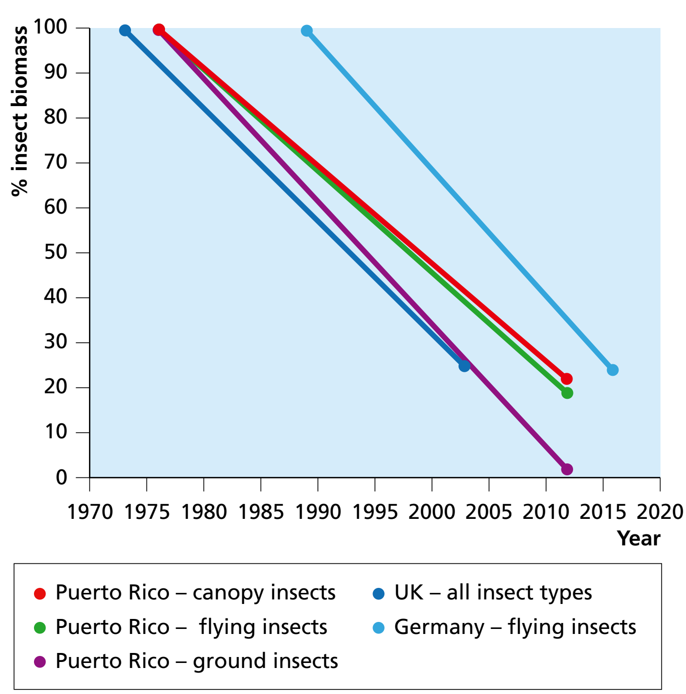

Figure 1 Insect biomass found in case studies. Linear trendlines are fitted between the start and end points of each case study

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government in September this year. A recent review of insect numbers across the world suggests that more than a third are undergoing 'dramatic rates of decline'. Bees, ants and beetles are disappearing eight times faster than mammals, birds or reptiles.

Leaf blower badness

Leaf blowing can cause catastrophic physical damage to insects but there are two additional problems with leaf blowers. A test conducted by a vehicle manufacturer in 2011 showed that a fossil-fuel-powered leaf blower emitted more pollutants than a large SUV. The California Air Resources Board found that 1 hour of operating a leaf blower emits 498 times more hydrocarbon, 49 times more particulate matter, and 26 times more carbon monoxide than the average petrol-driven car releases in an hour. Pollutants and climate warming are two significant factors in insect decline, estimated to be responsible for more than 3% and 5% of the decline respectively (see **www.tinyurl.com/r26roma**).

Another factor, which has only recently been identified as a problem for many insects, is noise. Leaf blower noise has been measured at 75 decibels from 15 metres away. The World Health Organization recommends that noise levels should be restricted to 55 decibels or less; prolonged noise levels over 75 decibels cause hearing loss in humans. The behaviour of many insects is strongly influenced by noise. Research on ants has shown that noise decreases their ability to navigate, their short-term memory and their brood caring behaviour, and increases their aggression towards nestmates. A study carried out in an area with compressor noise revealed dramatic differences from noise-free locations in abundance of insects and spiders that rely on sound or vibration (e.g. for finding a mate or prey).

Other threats to insects

Leaf blowers are only one of the many anthropogenic problems faced by insects. More than a third of insect decline is estimated to be attributable to intensive agriculture and pesticides. Declines in almost all regions of the world have been predicted to lead to the extinction of 40% of insects over the next few decades. One-third of insect species are now classed as endangered, but some species are likely to boom. A few tough, adaptable, generalists, such as houseflies and cockroaches, are able to thrive in a human-made environment and have evolved resistance to pesticides. As one researcher recently warned: 'It's quite plausible that we might end up with plagues of pest insects, but lose all the wonderful ones that we want, like bees and hoverflies, butterflies and dung beetles'.

Weblinks

Leaf blowers fatal to declining insects, Germans warned. 15 November 2019: **www.tinyurl.com/shd6teb**

Global insect decline may see 'plague of pests'. 11 February 2019: **www.tinyurl.com/yxybdbnq**

Alarm over decline in flying insects. 19 October 2017: **www.tinyurl.com/y7tjn7fb**

Is noise pollution making desert bugs disappear? 2 June 2017 **www.tinyurl.com/weloms9**

Activities

Join Buglife and you will be supporting their vital conservation work across the UK: **www.buglife.org.uk/product/membership**

Get involved by helping with a Buglife campaign in your school or college: **www.buglife.org.uk/campaigns**

See a neighbour using a leaf blower? Volunteer to sweep their leaves manually!

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