spotlight

Finding Nemo's mother

Life on a coral reef

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

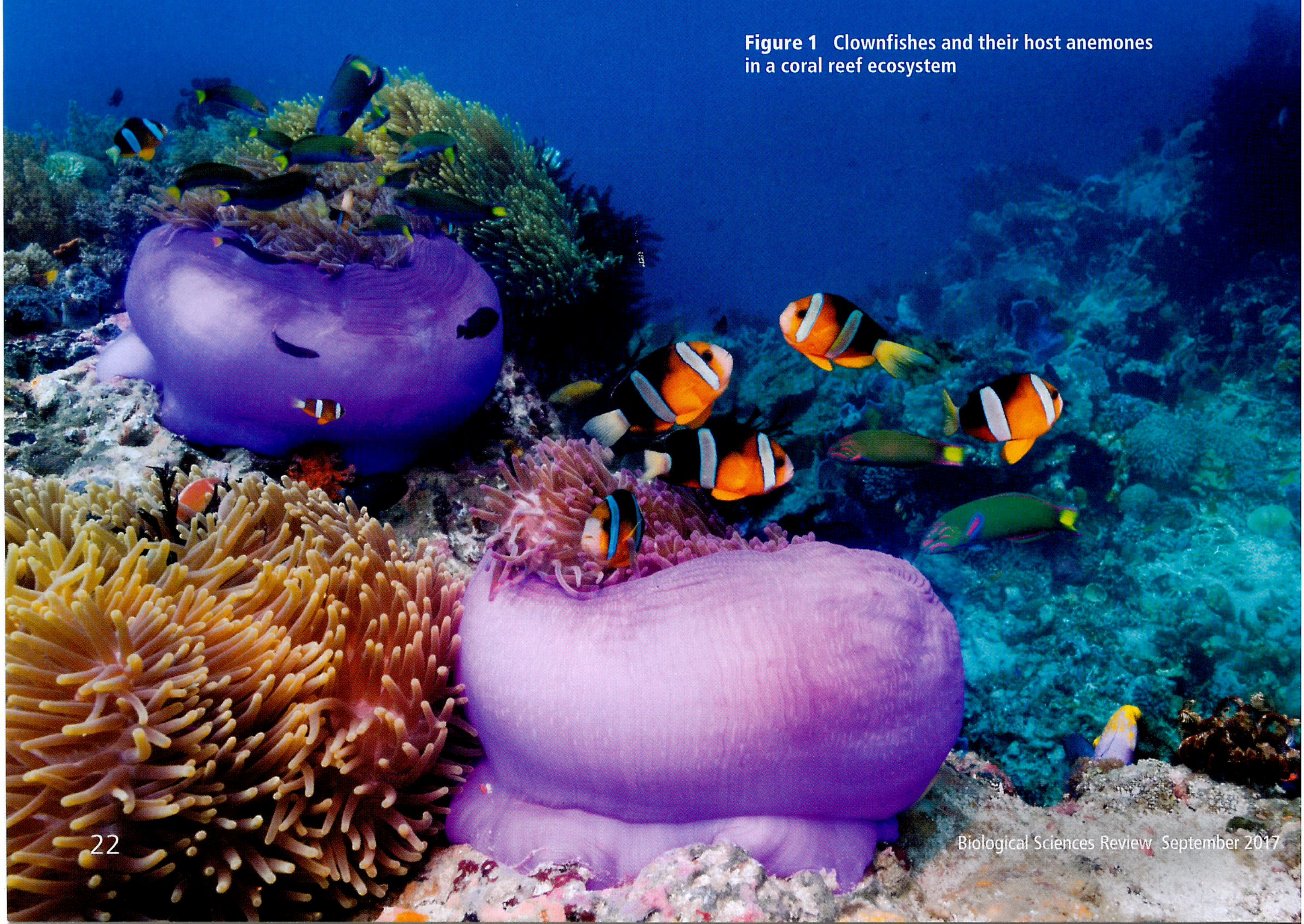
As in the film *Finding Nemo*, clownfish do live 'in' anemones. The fish benefit from the protection afforded by the stinging tentacles of their host, but are themselves unaffected, probably thanks to their thick mucus covering. The anemones gain protection from their own predators, as resident clownfish aggressively defend their hosts. Movements of the fish also stir the water around the anemones, increasing the amount of oxygen that reaches their hosts. And waste products from the fish provide valuable nutrients for the anemone. So the relationship between clownfish and anemones is described as a mutually beneficial **symbiosis**.

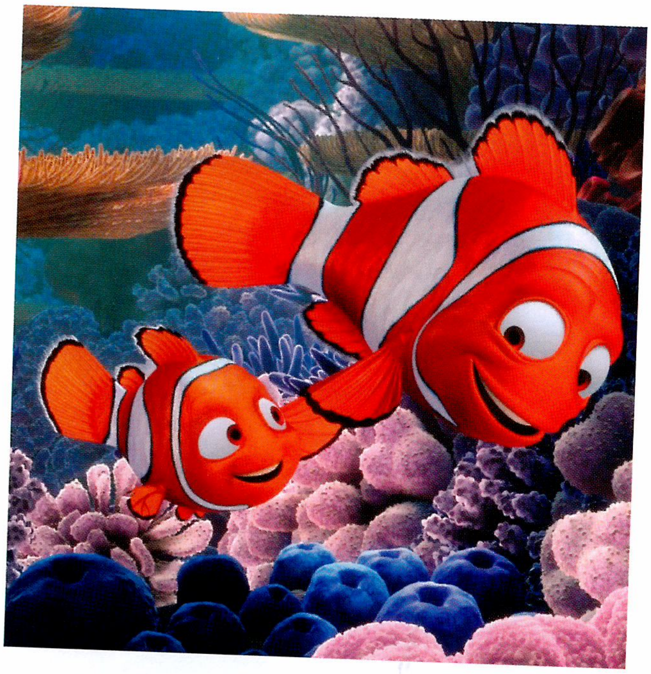
Key words

- Ecosystem
- Sex change
- Climate change
- Conservation
- Coral reef

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

Figure 1 Clownfishes and their host anemones in a coral reef ecosystem





over and over again, until the 200–1000 eggs in a clutch have been fertilised.

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

Clownfish hierarchy

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

Coral reef ecosystems

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

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

Much of the photosynthesis carried out in coral reefs occurs inside animals. Soft corals, such as the finger coral shown in Figure 2, have single-celled photosynthetic partners living inside them. These single-celled organisms are algae — a non-scientific term used for a huge collection

Box 1 Sequential hermaphroditism

In an intact hierarchy (see Figure 1.1a) the female runs things. Making clacking sounds with her jaws, she gives orders to the subordinate male and the gentlemen-in-waiting. If she is removed or dies, the male begins to show aggression and dominance, and courts the smaller fish (see Figure 1.1b). His brain controls these behavioural changes, but we know relatively little about the mechanisms that underlie his sex change to female.

Changes in the brain are transmitted along a pathway from the hypothalamus to the pituitary gland and then to the gonad. A gonad is a reproductive organ and male clownfish have an ovotestis — including both male (testicular) and female (ovarian) tissue. The ovary is in an immature state, with only oogonia and primary oocytes. Once sex change starts, the testicular tissue degenerates and ovarian tissue matures. By the time it is over, the fish can lay eggs, but can never recover the ability to make sperm. Steroid hormones, especially oestrogen, are thought to be key regulators in this process.

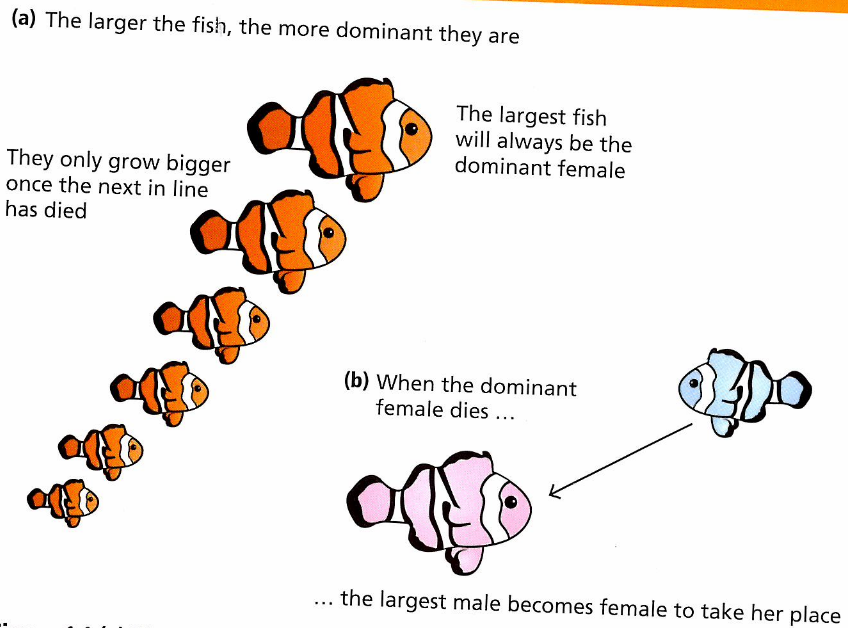


Figure 1.1 (a) Hierarchy **(b)** Sequential hermaphroditism

Figure 2 Close up of *Sinularia* — a finger coral ×3

of photosynthetic organisms living in wet places that range from massive seaweeds to tiny blue-green bacteria only visible under high magnification in an optical microscope. They all have the green pigment chlorophyll, but many have accessory pigments of oranges, reds or browns, that give their hosts their characteristic colours.

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

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

Coral bleaching

The balance between plant and animal in a coral symbiosis can be disrupted by both biological and environmental factors. If the algae succumb to disease, their pigmentation (and hence colour) is lost and the calcium carbonate skeleton of the animal becomes visible through their transparent tissues (see Figure 4). Since the 1980s it has become

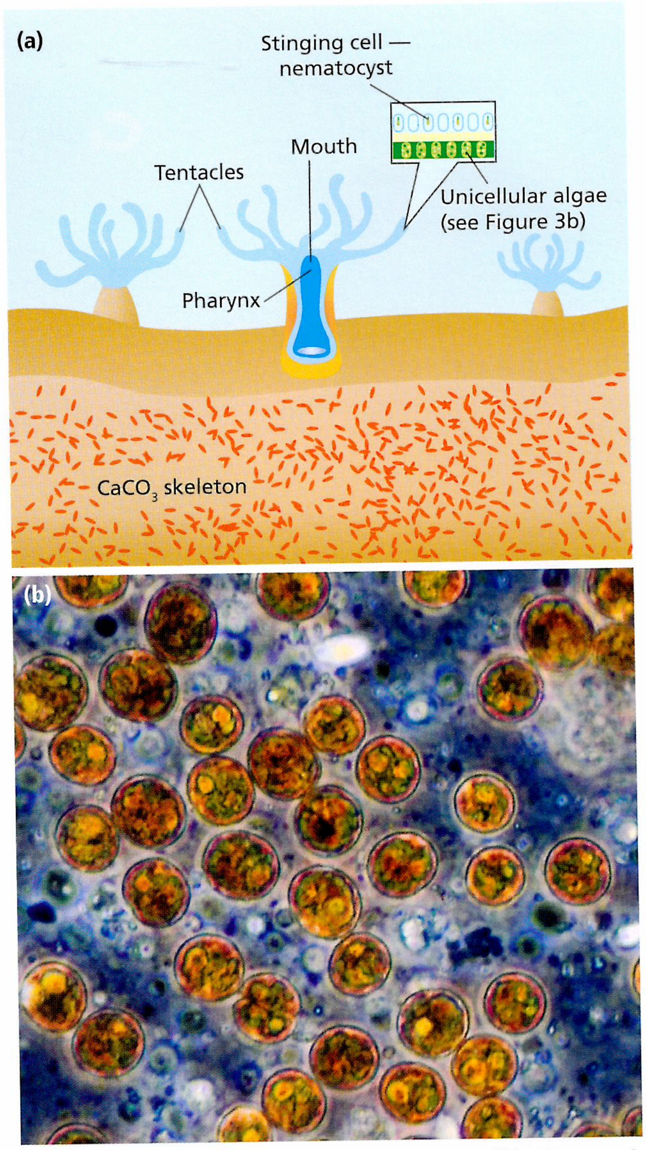


Figure 3 (a) Diagram explaining coral anatomy **(b)** Microscopic image of symbiotic algae inside a *Sinularia* coral ×1000

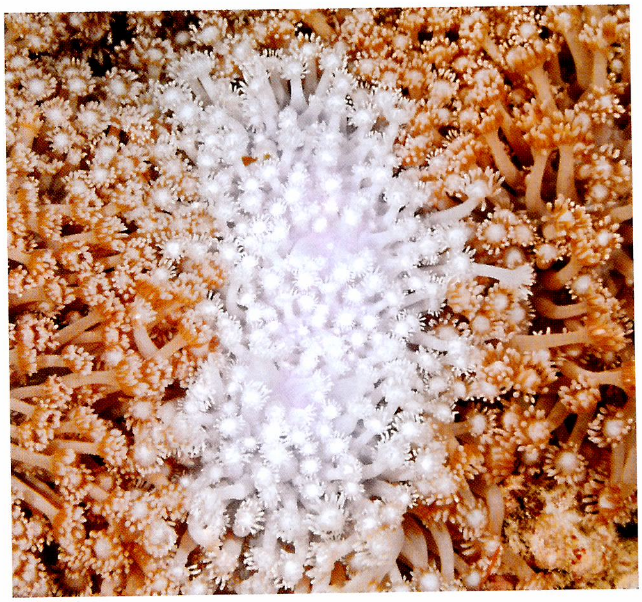


Figure 4 Bleached area of *Goniopora* — a hard coral

Further reading and viewing

Superb footage of clownfish (anemone fish) including an attack on a diver: **www.youtube.com/watch?v=8rSlA_ywEec**

More on coral bleaching and climate change: **www.globalcoralbleaching.org**

'Heat-tolerant genes could help corals adapt to climate change', *New Scientist* 25 June 2015: **https://tinyurl.com/kln78rl**

'Don't find Dory' — an explanation of why you should not buy a blue tang: **www.youtube.com/watch?v=0-8Uc-FLrml**

Box 2 Threats to coral reefs

While water temperature poses the greatest problem, corals face several other **anthropogenic** challenges. The use of fossil fuels has led to acidification of waters all over the Earth. Burning fossil fuels generates waste gases including sulfur and nitrogen oxides, which combine with atmospheric water to form acids. Carbon dioxide released from fossil fuel use combines with seawater to make carbonic acid — further acidifying the oceans. The skeletons of corals are based on calcium carbonate, which dissolves in acid. The lower the pH of seawater, the more coral animals struggle to secrete their skeletons and the slower their growth.

Herbivorous fish graze on free-living algae on the surface of corals, keeping the corals clean and allowing their symbiotic algae to photosynthesise. Over-fishing reduces the numbers of these grazers, and allows seaweeds to grow over the coral surfaces, blocking out sunlight and eventually killing the coral. **Eutrophication** can produce a similar effect. Coral reef waters are usually too nutrient-poor to allow prolific growth of seaweeds, but the addition of extra nutrients can tip the balance and cause rapid colonisation of coral surfaces.

Dynamite fishing — the process of dropping explosives into the water to stun or kill fish — is exceptionally deleterious for coral reefs. I was recently diving in Indonesia, where huge tracts of the underwater environment (and the beaches) are strewn with dead coral rubble generated by dynamite fishing. Although the practice is now illegal, it still goes on in some areas and recovery takes many decades.

Terms explained

Anthropogenic Human-induced change.

El Niño event A natural phenomenon that occurs when trade winds weaken in the central and western Pacific. Surface water temperatures off South America warm up, because there is less upwelling of cold water from below.

Eutrophication Excessive concentration of nutrients in a body of water, e.g. from agricultural run-off from land, which causes dense growth of aquatic plants.

Spawning The release of eggs and sperm into water.

Symbiosis *sym* = together; *bios* = life, so the word simply means organisms living closely together. Some relationships are deleterious to one of the partners, e.g. where one is a parasite; others are beneficial to both – referred to as mutualism.

Thermal tolerance The entire temperature range that permits survival of a species or symbiosis.

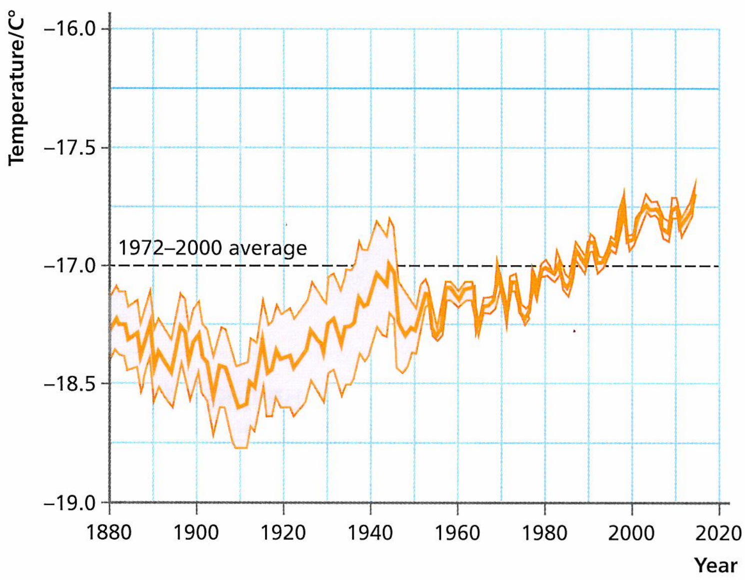


Figure 5 Average surface temperature of seas worldwide 1880–2020. The shaded band shows the likely range as there were few accurate measurements taken at the time

increasingly clear that global warming is causing large-scale coral bleaching. When the **thermal tolerance** of the symbiosis is exceeded, coral animals react by destroying or expelling their algae. Even without global warming, natural fluctuations in the Earth's temperature can make things worse. The **El Niño event** of 1997–98 was blamed for wiping out 16% of the world's shallow reefs.

Although coral reefs occupy only about 0.1% of our oceans, it is estimated that they support about a quarter of all marine species. They are especially important to juvenile fish, which rely on them for shelter while they grow to sufficient size to enter the open ocean, so coral reefs are vital to the 500 million or so people who rely on these fish for their food or income. An estimated 93% of the heat generated by global warming is absorbed by our oceans, so seas the world over are now significantly warmer than they were (see Figure 5). This is why research is underway, aimed at understanding how some reefs cope better with threats than others, and therefore might provide materials we could use to aid reef recovery.

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

Professor Liz Sheffield is chair and plant science editor of Biological Sciences Review. She is associate pro-vice-chancellor (education) in the Faculty of Science and Engineering in the University of Liverpool — the first university to teach marine biology in the UK and a centre of excellence for teaching and research in ocean sciences.