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In the pink:
Colour from carotenes

Think of amplification and you probably imagine a band on stage next to huge speakers. But things other than sound can be amplified, and not just by electronics.

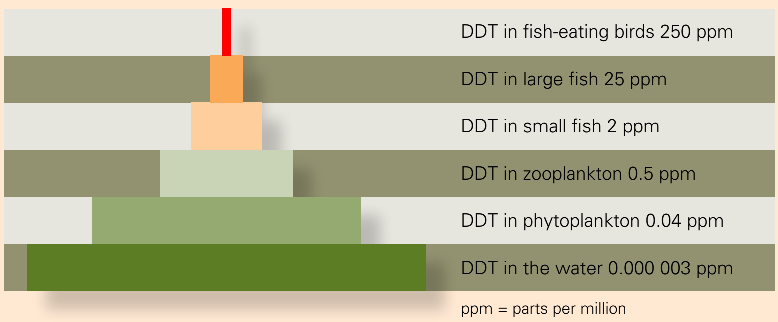
In nature, *bioamplification* causes substances to become more concentrated as they move from eater to eaten along a food chain. You may have heard this story in relation to the concentration of pesticides like DDT along a food chain, and how this causes problems for those animals, like birds of prey, at the top (see Box 1).

However, bioamplification can be more benign than that. It leads to much of the colour in nature. For example, in birds, there are three main sources of their (often striking) colouration: melanin pigmentation, structural colouration and carotenoid pigmentation. Melanin is made in the animal's own body and structural colours come from the way feathers interact with light, but carotene pigments come, in many cases, from the diet and are amplified along a food chain and concentrated in parts such as feathers, beak or skin.

Box 1 Bioamplification

The concentration of DDT, a pesticide still in use in some parts of the world, is amplified up a food chain by a factor of 10 million or more.

Bioamplification also gave rise to Minamata disease in Japan. Mercury-containing compounds from industrial processes were released into the sea. They accumulated up the food chain until people who ate contaminated tuna became seriously ill. Of the 10 000+ known victims, over 1800 died.



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Salt lake life

First then to the world's salt lakes, the most famous probably being the Great Salt Lake in Utah, USA. At certain times of year this lake has a green appearance in the water due to vast numbers of a tiny alga called *Dunaliella* (Figure 1).

Figure 1 *The green colour of this lake is caused by the presence of the* Dunaliella *alga whose cells contain chlorophyll..*

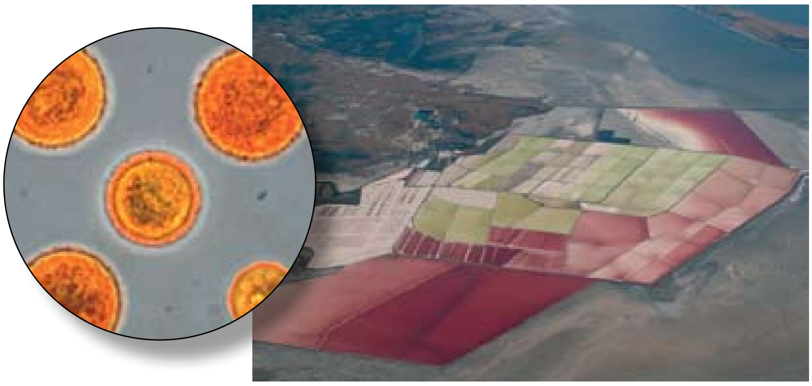

Figure 2 *The red colouring of these salt ponds in San Francisco Bay is due to the presence of* Dunaliella.

As plants, these algae make food in the process of photosynthesis and are at the base of a short food chain in this and other similar lakes. From the glucose they make in photosynthesis, with the addition of a few minerals, they can make everything else they need. Included in what they make is a pigment called carotene, found in abundance in nature, famously in carrots. This carotene is most obvious in the older algal cysts, which are reddish and, in huge numbers, give the lake water a red colour too (Figure 2).

Up the food chain

The main consumer of the algae is a small crustacean called the brine shrimp (*Artemia salina*). These are one of the few animal species which can live in the very salty water, and they therefore get most of the available algal food. Their numbers are, as a consequence, vast. At a point in their life cycle, the *Artemia* also form cysts containing concentrated carotene which gives the egg-like cysts an orange colour.

Brine shrimps, Artemia, *one male and one female (with eggs). Brine shrimps live in inland salt lakes but not in the sea.*

This carotene helps to protect the embryos inside the cysts, which can stay viable for many years.

Box 2 Carotene as a protective antioxidant

Most molecules from which living things are made are subject to oxidation, and this can produce free radicals which, in turn, can damage cells, leading to such diseases as cancer. The cysts of brine shrimps, being highly desiccated, are very susceptible to oxidation and free radical damage, but this is avoided by high levels of carotenoid pigments.

In one short food chain the brine shrimps are fed on by flamingos (although not in the Great Salt Lake). These birds have a highly specialised beak to be able to take advantage of this abundant, but tiny, food. The beak acts as a sieve allowing the bird to process large volumes of water and extract a lot of food in a short time (Figure 3). The carotene ends up in the flamingos and, yes, is the source of their pinky-orange colour.

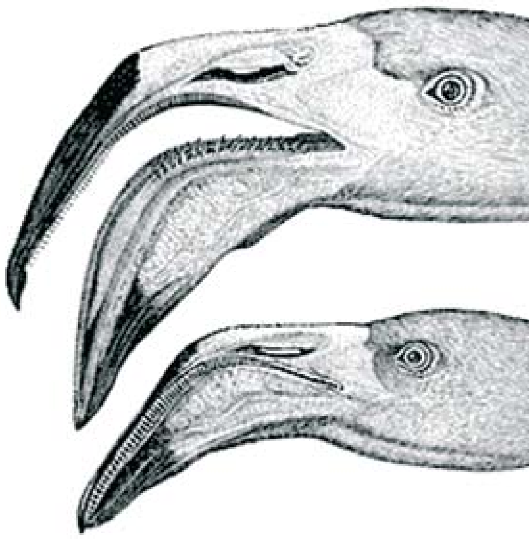

Figure 3

make them in the first place? The simple, and not surprising, answer is photosynthesis. The carotenes are, of course, pigments and as such they absorb light, the very thing plants need to do to make sugar from carbon dioxide and water. Chlorophyll is the main light absorbing pigment, but it only absorbs red and blue light, hence its green colour – see Figure 4.

Flamingos are born white and gain their pink colour from the carotenes in their food which they take in through their filter-feeding beak.

Figure 4 *Plants look green because they reflect the green part of the visible light spectrum.*

An absorption spectrum shows more clearly the extent to which different wavelengths of light are absorbed by a pigment. The absorption spectrum of chlorophyll is shown in Figure 5a; the two 'bumps' show that chlorophyll absorbs strongly at the low and high wavelength ends of the spectrum.

When flamingos are kept in captivity, as they often are, this specialised diet is difficult to provide, and they will feed on other things. They would not be pink if they were not given a dye in their artificial food. Zoos usually add something called Roxanthin Red to the food, and indeed there are companies who supply Flamingo Food (e.g. Flamingo Fare) which contains this and other carotene-related compounds.

But the role of carotenoids in making nature beautiful does not end with flamingos. The red bill of the zebra finch, the yellow one of the blackbird, the yellow of canary feathers and many of the colours we find in fruits and vegetables are, at least in part, due to carotene and related compounds. The role of carotene and its relatives in birds was first proved in 1934. Canaries were fed on an artificial diet free of carotenes and ended up with white feathers!

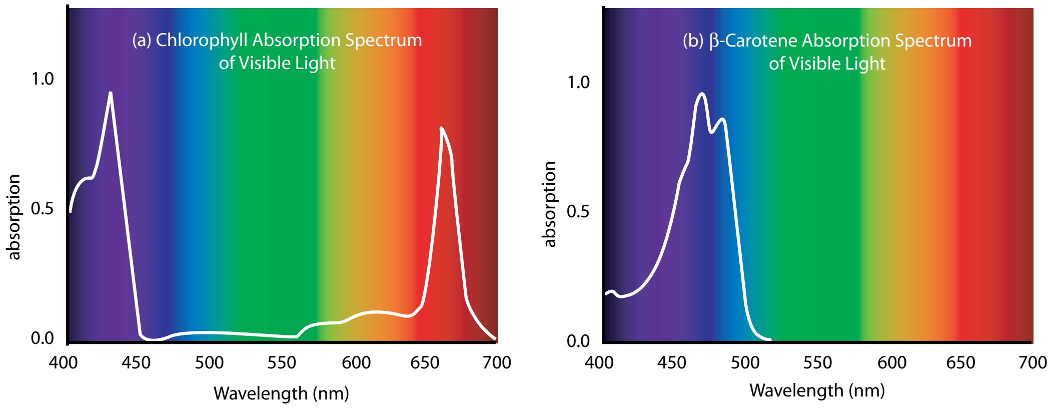

Figure 5 *Absorption spectra of* ***(a)*** *chlorophyll, and* ***(b)*** *β-carotene.*

Plants and carotenes

So plants make carotenes, which animals cannot do, and then animals acquire these and use them to protect themselves against free radicals (Box 2) and to produce mate attracting colours, warning colours and so on. But why do the plants

All the green and yellow light is reflected and thus wasted. It is not surprising to realise that carotenes absorb different coloured light from chlorophyll; they are after all a different colour. The carotene absorption spectrum is shown in Figure 5b. This shows that the carotene is filling in some of the wavelengths that the chlorophyll does not absorb. Plants have many such accessory pigments which absorb light energy and pass it to chlorophyll for photosynthesis.

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