The unique visual systems of deep sea fish

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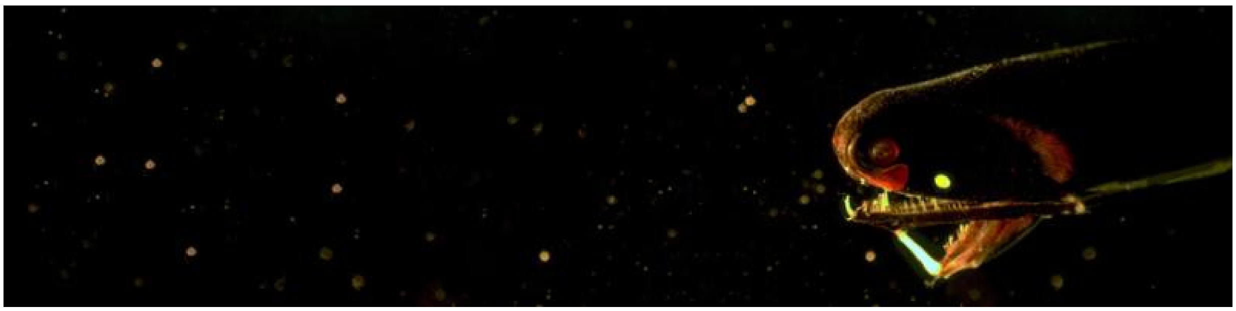

Credit: City University London

If asked the colour of the ocean, most people would rightly say "blue." The reason is that pure water absorbs long wavelength red light very strongly, but lets the shorter blue wavelengths pass. If you cut yourself while diving, for example, you do not bleed red. What comes out is an alarming brown/black colour.

If you are lucky enough to have dived in a submarine and looked out of the windows, as it gradually sinks towards the sea floor many miles below, you will notice that the sunlight gets gradually bluer and of course dimmer and eventually disappears altogether at about 1000m depth in the clearest waters.

However, the average depth of the ocean is 4000m and is over 10,000m in the deepest trenches. Yet, although sunlight is not available throughout most of the ocean, the majority of the animals living there have perfectly good eyes. What they are looking at is not sunlight, but light produced by other animals. As blue light travels furthest through the water, such bioluminescence, like any remaining sunlight, is usually blue.

It is therefore no surprise that most deep-sea fish have eyes that are only sensitive to blue light. There is no point wasting energy trying to detect light that isn't there.

The only exceptions are three types of deep-sea dragon fish. They not only produce red light from light organs under their eyes, they also have eyes sensitive to this part of the spectrum. This gives them the unique advantage of being able to signal to each other – usually for reproduction - or to illuminate things they are hunting using their red lights, immune from detection by potential predators and prey who cannot see long wavelengths.

Two of these dragon fish are sensitive to red light using similar mechanisms by which, for example, humans see this colour. The third, which is known as the loose-jaw dragon fish (Malacosteus niger), however sees red light in another way that involves using a form of chlorophyll, the pigment normally used by plants and some bacteria to absorb energy from light. No other animal does this.

Our research into the eyes of these animals was motivated simply by curiosity. We wanted no more than to see what these animals saw and how they saw it. However, other people have taken our observations and found that chlorophyll-like substances are in fact easily taken up by the eyes of animals that do not normally contain them and have suggested this may be a way of alleviating, for example, night blindness and even treating retinal neurodegenerative disease. A lovely example of pure research unexpectedly leading to potential clinical benefits.

One of the many open questions about the unique chlorophyll-based visual system of Malacosteus is where it gets its chlorophyll from. The form of chlorophyll its eyes contain is otherwise only found in bacteria that live in the mud, to which dragon fish have no direct access. A therefore colleague suggested to us that the chlorophyll might be provided by bacteria actually living in the eyes of Malacosteus. This idea is not as far-fetched as it might seem as endosymbiotic bacteria are vital for many processes in most animals. Humans, for example, could not survive without the bacteria that live in their gut.

There was also another reason why this may be a good hypothesis. In 1908 a German scientist on board the famous Valdivia oceanographic expedition, had observed a layer of cells in the retina of Malacosteus that no other animal had. It seemed possible to us that this is where the bacteria might live, especially after we saw that this layer of cells contained spheres of just the right dimensions to be bacteria.

The current paper, which is published in Scientific Reports1, was our attempt to prove this idea. To some of our colleagues, however, the idea seemed distinctly odd. However, no one would ever have guessed that this animal used chlorophyll to see with, so why not one more surprise?

The research was co-ordinated by City but it also involved researchers from laboratories in Bristol, Tübingen and Perth. To further investigate the origins of the chlorophyll we used material gathered over more than 10 years during expeditions aboard four different research vessels from 3 countries to the Pacific and Atlantic oceans.

We examined the retina of Malacosteus using light and electron microscopy, localised the bacteriochlorophyll using two cutting edge techniques, and above all isolated 135,000 active genes from the eye of this animal. A monumental amount of work that spanned several years.

Disappointingly, the result of all of this effort was to show that there was no trace whatsoever of bacteria living in the eyes of Malacosteus.

But real science is like that. You have no idea what you will find. If you did, it would not be worth doing. Unless you take risks and follow often strange ideas you will never find anything novel.

We now think, as we had in fact suggested several years ago, that dragon fish get their chlorophyll from their diet, potentially explaining a puzzling fact about this species. Malacosteus has fearsomely big teeth and is clearly 'designed' to eat other fish, which is what all its close relatives do. However, very surprisingly, its diet is made up not of fish, but consists of copepods, a group of tiny crustaceans for eating which large teeth seem superfluous. It transpires that the copepods dragon fish eat, unlike Malacosteus itself, have access to bacteriochlorophyll-containing anaerobic bacteria, thus potentially explaining why Malacosteus snacks on animals its fearsome jaws seem not be 'designed' for.

More information: Ronald H. Douglas et al. Localisation and origin of the bacteriochlorophyll-derived photosensitizer in the retina of the deep-sea dragon fish Malacosteus niger, *Scientific Reports* (2016). DOI: 10.1038/srep39395

Provided by City University London