COVER ILLUSTRATION

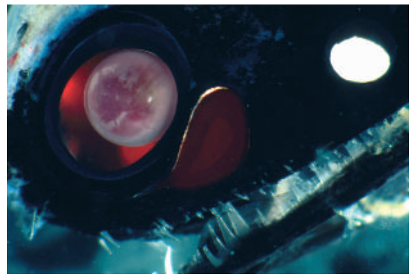
Blue light special in a red light district

Consider the fact that darkness continuously shrouds more than two thirds of the earth, since light does not penetrate much below watery depths of 1000 metres, and only does so in the cleanest and clearest of tropical seas. Consider further that the sun's rays illuminate any earthly surface during only half the day, and one can understand the evolutionary selection for animals to make their own light. Many do just that.

At depths of a few hundred metres or more, sunlight is restricted to a narrow spectral range of between 460 nm and 490 nm. Not surprisingly, bioluminescence emitted by almost all animals at this depth and deeper, even to abyssal depths, has a similar spectral range, with a peak at approximately 475 nm. Evolutionarily, it is the exception that proves most interesting.

The stomiid fish as represented by *Malacosteus niger*, the deep sea dragon fish, on this month's cover, have two different forms of bioluminescence. The usual bluish range of emission is produced by a retro-orbital light organ, but in addition to this organ there is an infraorbital organ located beneath the eye, as seen on the cover, which actually emits red bioluminescence. This unique appendage allows *M niger* not only to view prey that do not see these wavelengths, but also to communicate intraspecifically. *M niger* lives in a realm without sunlight, dominated by animals that produce and are visually sensitive to bioluminescence in the 460–490 nm range (we would call this "blue" light). *M niger* is an exception, with what could be described as "red vision goggles."

Such an unusual lifestyle requires several adaptations that defy imagination, indeed perhaps even investigation. *M niger* and two other similar mesopelagic fish are members of the three deep sea dragon fish genera having two different photophores, one producing bioluminescence in the shorter wavelengths between 460–490 nm. This is a common spectral range for bioluminescence in deep water fish, as nearly 80% of such fish produce light in this range coincident with the downwelling space light spectral range. But, in addition, these three genera have bioluminescent organs that produce light with much longer wavelengths. For *M niger*, that



spectral emission peaks at wavelengths beyond 700 nm (the longest wavelength humans can see is approximately at 700 nm and we would call this colour deep red).

Emitting light with two restricted spectra requires different visual pigments and other adaptations to interpret those signals, and evolution has responded with unusual selections.

M niger has a heavily pigmented lens that appears yellow to our eye, at least when brought up from its home at approximately 1000 metres below sea level. The absorption profile of this unusual lens has two maxima—one at 429 nm and one at 460 nm, although the absorption appears to be related to lens size, and hence is age dependent. As the fish and eye grow larger, the lens has a higher optical density at 429 nm (Douglas *et al*, *Prog Ret Eye Res* 1998;**17**:597–636). These unknown lenticular pigments restrict the shorter wavelengths perhaps to enhance the perception of bioluminescence or to break the camouflage of it (*BJO* 2001;**85**:1148).

M niger has an astaxanthin based tapetum, the layer that causes eyeshine. This deep red tapetum, seen easily on the cover, presumably will further enhance the sensitivity to the longer wavelengths that are emitted from the infraorbital photophore by giving the photoreceptors two chances to respond to the incoming photons. (Incidentally, the space seen around the lens is called the aphakic space, is not an artefact, and deserves an essay of its own.)

Still, most fish at such depths do not have the requisite visual pigments and cannot see the longer wavelengths at all. This includes any predators for *M niger*, so the tapetal reflex does not risk exposing the fish to predator or prey.

So, how does *M niger* do it? Not surprisingly, this fish has developed two visual pigments that respond to longer wavelengths, but with only a maximum absorbance at approximately 517 nm and 542 nm. That would not seem to be high enough to maximise the reception of the red stimulus. Further testing reveals that the outer segments of the retina of *M niger* do have photopigments with absorption at approximately 667 nm, but these pigments are not bleached by light. In other words, although it is a pigment that absorbs light, it does not send a neurological signal on that basis. Douglas and others have shown that this third retinal photopigment is a photosensitiser (Douglas *et al*, *Vis Res* 1999;**39**:2817–32), much like certain medications or foods in humans. This photosensitising pigment is coupled with the two true visual pigments to secondarily stimulate them to respond to the longer (red) wavelengths, so that *M niger* may use these longer wavelengths emitted from its own photophore to find prey or for intraspecies communication.

But, the next point about this fish is the most interesting. The photosensitising pigment is derived from chlorophyll! Douglas *et al* have convincingly shown that this chlorophyll derived photosensitising agent will respond to the longer wavelengths and result in excitation of shorter wavelength visual pigments making it a very special form of "blue light." Although no vertebrate is known to produce chlorophyll, certain copepods contain it, and *M niger* feeds primarily on copepods. Yet, *M niger*'s chlorophyll is uncommon in animalia, including its prey, being found only in certain green sulphur bacteria that live only in the subtidal marine environment; hence it is not clear how this compound is obtained. Presumably, there are other sources, as yet undiscovered, that are utilised by *M niger*.

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Cover image by Justin Marshall.