Spectra of reef fish – a physics approach to colourful patterns

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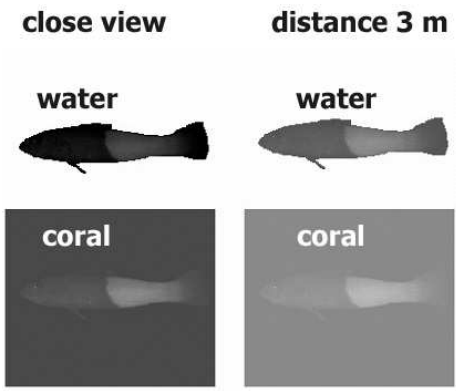
Coral reef fishes use brightly coloured body patterns for advertisement and camouflage. How are these conflicting demands combined? Simple inspection of colourful patterns of reef fish provides little insight into this problem, because fish vision differs substantially from ours. To investigate the utility of fish colours, we calculated the number of quanta absorbed by cone photoreceptors (cone quantum catches) in fish eyes viewing fish. These calculations were based on measurements of reflectance spectra of fish skin, spectra of light under water and spectral sensitivity of fish cone photoreceptors (Losey *et al.*, 2003; Marshall *et al.*, 2003). Cone quantum catches provide full description of colour, because surfaces that differ in their reflectance spectra, but yield similar quantum catch in photoreceptors, cannot be discriminated. To reconstruct views of a fish as seen through fish eyes, we encoded each point of a fish image with the set of quantum catches that were calculated for the reflectance spectrum in a corresponding point (Vorobyev *et al.*, 2001; Marshall & Vorobyev, 2003). This method allowed us to visualise the information available to fish brain, but it does not take into account the neural processing of photoreceptor signals.



The Figure shows a royal dottyback, *Pseudochromys paccagnellae*, as seen by an achromatic colour channel of a barracuda. We placed this fish against the background of water (upper panel) and of coral (lower panel). The head of this fish provides little contrast with coral, while the highly contrasting tail may serve as a signal. This fish usually hides its tail in the burrow and exposes its head. Many reef fishes are sensitive in the UV part of the spectrum, but none of them have photoreceptors that are sensitive to orange and red. Therefore, bright for our eyes red and orange colours of many reef fishes may look dull for fish. Often patches of skin that look red for us reflect in the UV-blue part of the spectrum; these reflectances yield signals in UV or blue sensitive photoreceptors in fish eye, and may strongly contrast with yellow patches that usually absorb in the UV-blue part of the spectrum. Since the illumination spectrum varies significantly under water, fish colours also change. Another important physical factor that affects colour appearance is spectrally selective absorption and scatter of light by water. One of the consequences of light scatter is a veiling effect, which reduces contrast (the Figure, right column). Since scatter is most prominent in the UV part of the spectrum, UV reflectance cannot be transmitted at long distance. Many small fishes probably use UV as a ‘secret communication channel’ that conveys signals visible at close distance, but is invisible for predators from long distance. Another trick, used by colourful fish to avoid being seen from far distance, is to combine strongly contrasting blue and yellow colours whose optical mixture is similar to the spectrum of background (Marshall & Vorobyev, 2003). Due to the scatter of light in water and the poor optical resolution of fish eyes, the body pattern of such fish cannot be resolved when viewed from a distance. Therefore a colourful fish appears to be well camouflaged.

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