

Cover illustration: An eye for an eye

Light levels at mesopelagic depths (200–1000 metres) are limited, creating unique problems for predators and their prey living at such depths. Evolution has responded with interesting and perhaps profound adaptations.

The slender javelin spookfish (*Bathylachnops exilis* Cohen) is a translucent mesopelagic fish with evolutionary adaptations so unusual as to seem unbelievable. Specimens of this fish have been taken at depths from as shallow as 30 metres to the extreme of 1000 metres. Evidence suggests that this fish is capable of nocturnal upward migration especially among the juveniles, and that the adults may live at depths as deep as 600 metres. For this species, endemic to the northern Pacific Ocean, prey probably consists of small crustaceans or coelenterates. *B. exilis* probably remains motionless until prey comes within range. Then, with short bursts of speed, this predator catches and crushes the prey within its mouth. This capture mechanism is predicated in part because of the lack of red muscle, thereby presuming a lack of myoglobin and/or haemoglobin, although this has not been determined. (Interestingly, this raises other questions regarding aerobic metabolism, and even retinal oxygenation, but we will save that for another time.) This suggests that the animal may not have much muscular reserve.

Unquestionably, the most startling anatomical aspect of this species is the second, smaller, ventrally located eye that buds directly off the limbus of the primary eye, as can be seen on the cover. The eyes are very large compared with the head size but that would be expected according to Haller's ratio which states that (relative) eye size varies inversely with body size. This expected globe enlargement would be further enhanced by the organism's evolutionary attempt at maximising light gathering potential at these mesopelagic depths, and this tendency occurs in most species at this depth. As is seen in many avian species, the septum between the globes is thin and the orbital structures are rudimentary, suggesting evolution has tried to maximise the relative and absolute globe size.

The photograph on the left of the cover is an external photograph of the head of this fish (this fish was approximately 53 cm in length). Note the translucent tissues that surround the eye, and note the ancillary eye near the anterior ventral aspect of the globe. The right hand photograph shows the enucleated specimen of a similar sized fish of the same species and the second completely formed eye on the lower left portion of the globe. This appendage is a retinal diverticulum with a completely formed lens, and an independent cartilaginous coat. The ganglion cells project their axons to the primary globe and single optic nerve exiting the main globe. The secondary eye is completely lined with retina and as the retina traverses the inner lens surface of the secondary lens, there is no retinal pigment epithelium and the retina is transparent, thus allowing light to pass through the secondary lens to stimulate cells in the retinal diverticulum. This diverticulum lining the secondary globe originates and connects to the primary eye through a small slit in the primary globe. Covering the slit is an operculum which blocks excess stray light that might scatter through the smaller secondary eye and enter the primary ocular cavity, although it strains the imagination how there might be stray light into any eye at this depth.

The primary eyes face anteriorly and dorsally with a 35° angle with the horizontal (Percy *et al*, *Nature* 1965;207:1260–2). This provides a rather large

stereoscopic field directed somewhat vertically above the horizontal. The smaller secondary globe, located rostroventrally, is directed ventrally, and perhaps a bit caudally, and is enclosed in scleral cartilage. In adult specimens the secondary globe may be as large as one half the diameter of the primary globe although this does not appear to be the case in juveniles. Additionally, there are two dense intrascleral masses along the lower orbital rim of the primary globe lined up distal to the secondary eye. These structures resemble the secondary lens and may allow for photoreception directly parallel to the horizontal, which would otherwise be a blind spot for the more dorsally focused primary eyes. This would permit a complete panorama of the entire inferior 180° of visual field and probably most of the frontal field although discrimination would be limited in much of that field. The true function of these extra lenticular-like masses, however, is not yet completely understood.

The retina is believed to be an all rod retina, although the visual pigment or pigments have not been determined. Presumably this single photopigment is tuned to approximately 475 nm, as are most known photopigments of fish predators at this depth, since this is approximately the frequency of bioluminescence. There appears to be a high degree of summation because of a dense nuclear layer and a progressive decrease of cells in the inner nuclear and ganglion cell layers. Rarely, other fish at this depth have evolved more than one pigment, so assumptions should be made carefully.

Neurologically, little is known, but the olfactory lobes and the optic lobes are described as large and bulbous, and the acousticolateralis system is also hypertrophic (Stein *et al*, *J Fish Biol* 1985;27:215–28). Other predators, especially at this depth, have evolved excellent olfactory abilities presumably to supplement the dwindling light at that depth. The binocularity of the fish suggests that it is a deep water predator.

The ecology of *B. exilis* is poorly understood, so little functional significance can be ascribed to the secondary eye and even less is known of the additional scleral masses. Presumably, the secondary globe is used to locate food or to avoid predation, and the scleral bodies may increase the visual field by focusing light from a benthic perspective, if they are lenses at all. Since the primary globes are believed to be used for prey detection, the secondary eyes may be used to avoid predation from below.

The evolutionary implications for this fish and its second pair of eyes are profound. Other deep water fish possess retinal diverticula without a secondary lens. Often fish that possess retinal diverticula have tubular eyes described as "telescopic" to maximise light collection at mesopelagic or bathypelagic depths. Fish within the same taxonomic group and related to *B. exilis* have retinal diverticula, but do not have anything resembling this secondary eye, suggesting that evolution can and does produce eyes rather quickly—in perhaps one million years or even considerably less. *B. exilis*, perhaps in its effort to extend the evolutionary quit point or in an evolutionary effort to expand its scavenging abilities, has evolved a second eye budding off from the first. This is powerful and profound evidence for those who would doubt natural selection.—Ivan R Schwab, MD, UC Davis Department of Ophthalmology, 4860 Y Street, Suite 2400, Sacramento, CA 95817, USA (irschwab@ucdavis.edu)

Specimens graciously provided by the Oregon State University, Department of Fisheries and Wildlife fish collection, Corvallis, OR, USA, through Dr William Percy and Dr Douglas Markle. Specimen numbers OS12443 and OS14840.

