

HOW DO FISH REACT TO LOW OXYGEN LEVELS?

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○ One of the basic principles of good aquarium maintenance is to make sure that water is well aerated. Adequate aeration ensures that enough oxygen is present in the water for fish respiration. Dissolved oxygen can come from the photosynthesis of aquatic plants, or it can simply diffuse from air to water. By blowing air bubbles into the water and by creating ripples at the surface, the aquarist increases the size of the air-water interface, thereby dissolving enough oxygen to maintain fish in good shape.

In nature, however, fish are often faced with situations where little oxygen is present in the water. In some places, stagnant water reduces the size of the air-water interface and minimizes the mixing of oxygen into the water. In other places, an overabundance of animals and decomposing matter in the water can lead to oxygen depletion through increased consumption. These situations are not uncommon, and so it is not surprising to learn that fish have evolved special behaviors to cope with low oxygen levels. If you are a good aquarist, you've probably never had cause to witness these behaviors. But behavioral scientists, being the curious lot that they are, have observed and catalogued the reactions of fish to "hypoxia" (the technical term for low oxygen levels). Here is what they have found.

A universal reaction to low oxygen is increased ventilation. In the same way that out-of-breath people start to breathe faster to bring more air to their lungs, fish increase the rate of water movement through their gills. One can easily witness this: In hypoxic waters, fish close and open

their gill covers at a faster rate than normal. For example, three-spine sticklebacks *Gasterosteus aculeatus* move their gill covers at a rate of 165 openings per minute when the water has only half of its normal oxygen content. This is a substantial increase over the normal rate of 95 openings per minute (Jones 1952). You should note, however, that other factors, such as stress and high activity, can also lead to increased ventilation.

After encountering an area of low oxygen content, fish often start to move rapidly and erratically. They

probably do this to escape the danger zone. However, if hypoxic conditions persist, most fish greatly reduce their general activity. For example, three-spine sticklebacks in natural ponds become rather sluggish during hypoxia, even failing to show normal flight responses when there is a risk of predation (Whoriskey *et. al.*, 1985). Guppies in the laboratory usually swim less, eat less, and court less when oxygen levels are lower than normal (Kramer and Mehegan 1981; Weber and Kramer 1983). Inactivity reaches extremes in the South American cichlid *Biotodoma cupido*, who enters a torpor-like state when oxygen is scarce (Cichocki 1977). The advantage of such a strategy is simple: less activity means less need for oxygen.

Another common response to low oxygen levels is aquatic surface respiration (ASR). In this behavior, fish stay just below the surface, put their snout at the air-water interface, and breathe in the film of water that is in direct contact with the air. This film of water is comparatively rich in oxygen. Aquatic surface respiration is widespread: in a study conducted at McGill University in Montreal, Don Kramer and Martha McClure tested 24 common species of tropical fish, going from tetras to barbs to cichlids, and they found that all species performed ASR when oxygen was deficient (Kramer and McClure 1982). Typically, fish waited until a very low threshold of oxygen concentration was reached before starting ASR. The apparent reluctance to perform this behavior is easy to understand when we consider that, in nature, many predators of fish are terrestrial animals attacking from above, and thus being close to

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the surface is very risky.

Some fish can also switch from water-breathing to air-breathing when there is not enough dissolved oxygen in the water. These fish break the surface and trap air inside their mouth. Then they use their mouth, pharynx, oesophagus, swimbladders and even sometimes their stomach like we use lungs, that is as a site where oxygen can diffuse into the blood. Examples of such fish include gouramis, goldfish, loaches, catfishes, *Plecostomus*, and the well-known lungfishes. As with ASR, air-breathing entails a substantial risk of predation because of the fish's necessary proximity to the surface (see Kramer, *et al.*, 1983). There is also the cost of having to travel between the surface and the depth at which the fish normally feed.

In parental species, several behaviors are influenced by oxygen concentration. For example, many species lay their eggs on a substrate and fan them. Fanning is an activity whereby the parent maintains a flow of water over the eggs by rhythmically moving its fins near them. Fanning is necessary because without it the breathing eggs would use up all of the oxygen present in the layer of water that surrounds them. The flow of water created by the fanning parent ensures that oxygenated water surrounds the eggs at all times. Given this, one would expect fish to fan more when dissolved oxygen levels are low. This has, indeed, been observed in sticklebacks in the field (Reebs, *et al.*, 1984); other formal reports are lacking; but it would be interesting to try to find the same effect in other fanning species such as damselfishes and cichlids.

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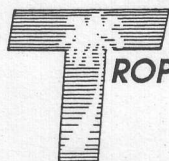
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A peculiar behavior has been observed in one species of cichlid, the rainbow cichlid, *Herotilapia multispinosa*. Working at the University of Western Ontario, Simon Courtenay and Miles Keenleyside exposed parental rainbows to low oxygen concentrations (2 ppm, down from 8 ppm). They observed that when the eggs hatched, the parents did not gather the emerging wrigglers into previously-dug pits as usual. Instead they took the wrigglers in their

mouth and spat them into vegetation, onto which the wrigglers attached themselves thanks to glue producing glands on their head. The researchers showed that this behavior, called "wiggler-hanging," is more prevalent when oxygen concentration is low. They surmised that wrigglers benefit from being close to vegetation because photosynthesizing plants release oxygen into the water, and because they are closer to the surface. Wiggler-hanging has also been reported in *Cichlasoma*



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festivum, *C. bimaculatum*, *Symphysodon discus*, and *Pterophyllum scalare* (see Courtenay and Keenleyside 1983, for more details).

Recently, one of my students has observed another peculiar behavior, this time in the convict cichlid *C. nigrofasciatum*. He had a pair of convicts tending their eggs inside a ceramic skull (one of those aquarium decorations sold in pet shops). The female, instead of fanning her eggs

in the usual way, used to go to the airstone, take air into her mouth, bring it back to the nest and release it at the bottom so that the air bubble would float upwards along the egg batch. She did this repeatedly, to the extent that air was gathering at the top of the skull, threatening to raise the nest and its content all the way to the surface! Did she carry air bubbles to provide oxygen to her eggs in the face of hypoxic conditions? We do not know because, unfortunately,

measurements of oxygen concentration were not taken. It would be interesting to see if this behavior could be elicited again by artificially lowering oxygen concentration in future experiments.

All in all, fish responses to low oxygen levels are diverse and widespread (more details can be obtained from Kramer 1987). Of course, these responses are not sufficient to allow fish to survive indefinitely in hypoxic waters. However, they can contribute to survival for several days. It is a comforting thought, one to which you can cling next time you are away from home on an extended leave, worrying about your air pump suddenly failing!

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