# DOES A FISH WITH LUNGS EXIST? MORPHOLOGICAL AND PHYSIOLOGICAL ADAPTATIONS TO AQUATIC HYPOXIA AND HYPEROXIA.


## Summary

Dissolved oxygen is one of the most important environmental factors affecting survival of fishes that rely on aquatic respiration. Fishes face an ever changing availability of environmental oxygen, resulting for instance from the dynamics of temperature changes, surface agitation, primary production by plants and algae, and oxygen consumption by plants, animals as well as chemical processes. In natural fish environment the oxygen levels exhibit a daily cycle, depletion (consumption) during the night, and production of oxygen that might lead to supersaturation levels of up to 300% during the day. At the organismal level, the lack of sufficient oxygen in environment (hypoxia) and oxygen oversaturation (hyperoxia), will result in the reaction of chemoreceptors, the respiratory response in brain, as well as in general metabolism, growth, behavior, and important morphological adaptations. In water-breathing teleost fish hypoxia induces hyperventilation, bradycardia, and results in an elevation in gill vasculatory resistance. The phenomenon of changes in the gill structure in *Carassius carassius* has been also described, which included lack of protruding secondary lamellae in normoxia due to complete embedding in intralamellar cell mass (ILCM). In hypoxic water a large reduction in ILCM occurred, making the lamellae to protrude and increasing the respiratory surface by about 7.5 fold. These morphological changes were found to be reversible and apparently caused by an increased apoptosis combined with reduced cell proliferation. Although, this seemed to be a plausible explanation, further studies did not unequivocally associate ILCM with normoxic conditions. Fish have also been found to adapt to extreme hypoxia or anoxia by employing alternate metabolic pathways for anaerobic energy production. Members of the genus *Carassius* are the only vertebrates that are known to produce energy by fermentation of glucose to ethanol and carbon dioxide. All physiological responses to hypoxia, and probably to hyperoxia, arise principally from peripheral chemoreceptors located in the gills (neuroepithelial cells, NECs). Additionally, hypoxia induced factor HIF-1α is a key transcription factor in mediating various responses to low level of oxygen.

Chronic or repeated challenges elicit responses that further modify the respiratory phenotype in ways that improve and regulate oxygenation in tissues. Aquatic hypoxia has been cited as the primary driving force in the evolution of air breathing in fish. The fish from order Semionotiformes (garfishes) and Polypteriformes (*Polypterus senegalus*) use respiratory gas bladder (RGB) and lungs, respectively, to acquire atmospheric oxygen. These organs may confer a high degree of independence from water quality to achieve the metabolic scope for activity and the ability to recover from hypoxia. Thus, the air-breathing fish, may not only survive aquatic hypoxia but may also maintain normal levels of activity when branchial $O_2$ uptake is limited. The evolutionary transition to air breathing has been accompanied by biochemical and morphological modifications of respiratory structures as well as altered ventilatory regulation. However, there is clearly an ontogenic aspect to this transition from unimodal gill and/or body surface respiration to bimodal, water and air respiration.